U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-269 576

Ambient Hydrocarbon and Ozone Concentrations Near a Refinery Lawrenceville, Illinois - 1974

Washington State Univ, Pullman Air Resources Section

Prepared for

Environmental Sciences Research Lab, Research Triangle Park, N C

May 77

PB 269 576

EPA

AMBIENT HYDROCARBON AND OZONE CONCENTRATIONS NEAR A REFINERY
Lawrenceville, Illinois
1974

Interagency
Energy-Environment
Research and Development
Program Report

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/7/77-049

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
AMBIENT HYDROCARBON AND OZONE CONCENTRATIONS
NEAR A REFINERY
Lawrenceville, Illinois - 1974

5. REPORT DATE
May 1977

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
H. H. Westberg, K. J. Allwine, and E. Robinson

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Air Resources Section
Chemical Engineering Department
Washington State University
Pullman, Washington 99164

10. PROGRAM ELEMENT NO.
1NE625B EA-01 (FY-77)

11. CONTRACT/GRANT NO.
68-02-1231

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Sciences Research Laboratory - RTP, NC
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/09

15. SUPPLEMENTARY NOTES

16. ABSTRACT

In the summer of 1974, a study was undertaken to establish the effect of refinery emissions on the air quality of a region. The refinery studied was operated by Texaco in Lawrenceville, Illinois. Air sampling was conducted from a ground based trailer and from aircraft. Results showed that the plume was readily detectable as far as 25 miles downwind. No increase in ozone was observed downwind of the refinery, probably because of the low reactivity of the hydrocarbons (mostly alkanes) and the very low levels of nitrogen oxides.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
* Air pollution	Photochemical reactions	Lawrenceville, Ill.	13B
* Refineries			13I
* Smog			04B
* Hydrocarbons			07C
* Ozone			07B
* Nitrogen oxides			14B
* Sampling			07E

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC

19. SECURITY CLASS *(This Report)*
UNCLASSIFIED

20. SECURITY CLASS *(This page)*
UNCLASSIFIED

21. NO. OF PAGES
107

22. PRICE
PC A06 | MF A01

EPA Form 2220-1 (9-73)

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

1a

EPA-600/7-77-049
May 1977

AMBIENT HYDROCARBON AND OZONE CONCENTRATIONS NEAR A REFINERY

Lawrenceville, Illinois - 1974

by

H. H. Westberg, K. J. Allwine and E. Robinson

Air Resources Section
Chemical Engineering Department
Washington State University
Pullman, Washington 99164

Contract No. 68-02-1232

Project Officer

Joseph J. Bufalini
Gas Kinetics and Photochemistry Branch
Environmental Sciences Research Laboratory
Research Triangle Park, North Carolina 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

DISCLAIMER

This report has been reviewed by the Environmental Sciences Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

In the summer of 1974, a study was undertaken to establish the effect of refinery emissions on the air quality of a region. The refinery studied was operated by Texaco in Lawrenceville, Illinois. Air sampling was conducted from a ground based trailer and from aircraft. Results showed that the plume was readily detectable as far as 25 miles downwind. No increase in ozone was observed downwind of the refinery, probably because of the low reactivity of the hydrocarbons (mostly alkanes) and the very low levels of nitrogen oxides.

CONTENTS

Abstract iii

Figures vi

Tables viii

Acknowledgement x

1. Introduction 1
2. Summary and Conclusions 3
3. Experimental Procedures and Conditions 5
    - Measurements 5
    - Calibration 7
    - Sampling Techniques 8
4. Results and Discussion 11
    - Refinery Description 11
    - Gaseous Composition of the Refinery Plume 13
    - Plume Dimensions 15
    - Downwind Plume Drift 21
    - Plume Chemistry 32

References 42

Appendices

A. Location and Concentration of Hydrocarbons, CO, and NO_x 43
B. Surface Measurements of Atmospheric Contaminants 77
C. Ozone Survey Flight Paths 90

Preceding page blank

FIGURES

Number Page

1 Lawrenceville area maps 12

2 Ground measurements at trailer site on June 14-17 14

3 Computer printout of a portion of the flight record for June 23 17

4 Plots of time vs. condensation nuclei, visual range, and ozone concentrations while traversing the plume at 8 miles 18

5 Plots of time vs. condensation nuclei, visual range, and ozone concentrations while traversing the plume at 2 miles 19

6 Plume width (based on elevated condensation nuclei levels) in relation to approximate dimensions of the refinery 22

7 Crosswind plume light hydrocarbon concentration as a function of distance 28

8 Centerline plume light hydrocarbon concentration as a function of distance 29

9 Light hydrocarbon chromatogram typical of the plume 33

10 Variations in hydrocarbon composition within the plume 34

11 Ozone recording taken during aircraft passes through the plume 38

12 Aircraft flight path on the afternoon of June 23, 1974 with ozone concentrations (ppb) marked at specific points along the route 40

13 Aircraft flight path on the afternoon of June 20, 1974 with ozone concentrations (ppb) marked at specific points along the route 41

FIGURES (cont.)

Number		Page
A-1	Location of hydrocarbon samples collected on June 13, 1974	44
A-2	Location of hydrocarbon samples collected on June 14, 1974	47
A-3	Location of hydrocarbon samples collected on June 15, 1974	50
A-4	Location of hydrocarbon samples collected on June 16, 1974	53
A-5	Location of hydrocarbon samples collected on June 17, 1974	56
A-6	Location of hydrocarbon samples collected on June 19, 1974	59
A-7	Location of hydrocarbon samples collected on June 20, 1974	62
A-8	Location of hydrocarbon samples collected on June 21, 1974	65
A-9	Location of hydrocarbon samples collected on June 22, 1974	69
A-10	Location of hydrocarbon samples collected on June 23, 1974	71
A-11	Location of hydrocarbon samples collected on June 24, 1974	74
C-1	June 13: Ozone survey flight	91
C-2	June 15: Ozone survey flight	92
C-3	June 20: Ozone survey flight	93
C-4	June 23: Ozone survey flight	94
C-5	June 24: Ozone survey flight	95

TABLES

Number		Page
1	Ground Measurements	6
2	Aircraft Measurements	6
3	Crude Capacity and Plant Emissions for Refinery June 13-24, 1974	13
4	Vertical Profile of Light Hydrocarbon Concentrations (μg/m)	20
5	Light Hydrocarbon Concentrations of Refinery on June 19	23
6	Hydrocarbon Dilution vs. Distance from Refinery	24
7	Crosswind Hydrocarbon Data	26
8	Plume Centerline Hydrocarbon Data	27
9	Hydrocarbon Ratios Within the Plume	37
A-1	Data from Ground and Airborne Samples, June 13, 1974	45
A-2	Data from Ground and Airborne Samples, June 14, 1974	48
A-3	Data from Ground and Airborne Samples, June 15, 1974	51
A-4	Data from Ground and Airborne Samples, June 16, 1974	54
A-5	Data from Ground and Airborne Samples, June 17, 1974	57
A-6	Data from Ground and Airborne Samples, June 19, 1974	60
A-7	Data from Ground and Airborne Samples, June 20, 1974	63
A-8	Data from Ground and Airborne Samples, June 21, 1974	66
A-9	Data from Ground and Airborne Samples, June 22, 1974	70
A-10	Data from Ground and Airborne Samples, June 23, 1974	72

LIST OF TABLES (cont.)

Number		Page
A-11	Data from Ground and Airborne Samples, June 24, 1974	75
B-1	Surface Measurements at Lawrenceville, Illinois on June 13	78
B-2	Surface Measurements at Lawrenceville, Illinois on June 14	79
B-3	Surface Measurements at Lawrenceville, Illinois on June 15	80
B-4	Surface Measurements at Lawrenceville, Illinois on June 16	81
B-5	Surface Measurements at Lawrenceville, Illinois on June 17	82
B-6	Surface Measurements at Lawrenceville, Illinois on June 18	83
B-7	Surface Measurements at Lawrenceville, Illinois on June 19	84
B-8	Surface Measurements at Lawrenceville, Illinois on June 20	85
B-9	Surface Measurements at Lawrenceville, Illinois on June 21	86
B-10	Surface Measurements at Lawrenceville, Illinois on June 22	87
B-11	Surface Measurements at Lawrenceville, Illinois on June 23	88
B-12	Surface Measurements at Lawrenceville, Illinois on June 24	89

ACKNOWLEDGEMENT

Our gratitude is extended to Dr. J. Bufalini, EPA Project Officer, for helpful suggestions concerning technical aspects of this work. The cooperation of Texaco, Inc., in providing information on design and operation of the Lawrenceville Refinery is gratefully acknowledged. Other colleagues at Washington State University who made important contributions to this program included D. F. Adams, R. A. Rasmussen, P. Weir and P. Zimmerman.

SECTION 1

INTRODUCTION

The modern petroleum refinery is a complex installation with a large number of potential air pollution sources and a wide variety of potential emission constituents. The monitoring or even checking of all of the possible sources in a refinery would be a practical impossibility. The Environmental Protection Agency's publication,[1] "Compilation of Air Pollution Emission Factors," lists 24 categories of sources within a refinery, ranging in size from huge catalytic cracking units to pipeline valves and flanges. Typically, the air pollutant emissions from the various units in a refinery are based on an estimation of loss as a function of the product throughput of the system. For example, the hydrocarbon emission factor for the category "pipeline valves" is given as 28 pounds per thousand barrels per day of refinery capacity. For a fluid catalytic cracking unit, the emission estimation procedure is similar, and the emission would be estimated on the basis of the EPA publication as 220 pounds per thousand barrels of fresh crude feed to the catalytic unit.

Although many refinery operators have monitored the emissions from particular units within their operation, most published estimates of the emissions from refinery operations relate back to EPA research studies carried out in southern California refineries in the 1950's.[2] It is readily apparent, therefore, that the assessment of the air pollution environmental impact of a major refinery is not a well defined procedure at this time and, furthermore, the data available may not even be up-to-date with regard to current refinery practices.

In an effort to improve the understanding of refining in pollution impact, Washington State University undertook a study of the nature of the plume from a major refinery located in a rural, low-background area. The relative isolation of the refinery with regard to other major industrial and urban sources was an important aspect of this study because it permitted the refinery plume to be uniquely identified. It was anticipated that results from this ambient atmospheric research study should be useful in assessing the nature of air pollution impacts from refinery operations, including both presently operating installations and proposed new refinery construction. Through correlations between estimated emissions, as based on engineering design and throughput and these atmospheric measurements, the results can be used to assist in the development of a picture of the interactions between atmospheric processes and the refinery source emissions. Although these research results can form a basis for assessing certain refinery impacts in areas other than the research area involved in this program, such an application must be made with a full accounting for changes in meteorology, topography, and other environmental factors.

Possible air pollution impacts from refinery operations include not only the emissions of primary contaminants from the various operations within the refinery complex but also a concern for possible atmospheric reactions involving these gases, resulting in the production of new and more harmful contaminants such as photochemical oxidants. Therefore, a significant part of this research program was directed toward an assessment of the downwind plume to determine whether photochemical reactions were occuring within the plume with subsequent production of photochemically related atmospheric products.

SECTION 2

SUMMARY AND CONCLUSIONS

In this research program we were able to establish a number of characteristics of the plume from a moderate-sized petroleum refinery in the Midwest. These can be summarized as follows:

1. Aircraft traverses of the refinery plume provided an excellent means of defining plume dispersion. Condensation nuclei counts, visual range (integrating nephelometer) and hydrocarbon concentration were used to define plume boundaries. The upper limit of plume dispersion generally coincided with the base of the mixing layer. At distances of less than four miles from the refinery, plume width corresponded closely to the dimensions of the refinery source area.
2. The typical plume at a distance of about 1-1/2 miles from the refinery showed NMTHC levels in the 1-2 ppm range, carbon monoxide concentration of 3-5 ppm, NO_x levels of 30 ppb and a decrease in ozone levels relative to areas outside of the plume. Background concentrations outside of the plume were generally less than .2 ppm for NMTHC, approximately .7 ppm CO and 15 ppb NO_x.
3. Transport of the refinery plume as measured by aircraft traverses showed that the plume could be identified on the basis of elevated hydrocarbon levels out to a distance of 25 miles. The degree of hydrocarbon dilution occurring in the plume was similar to what would be predicted using relatively simple atmospheric diffusion models both with regard to plume centerline concentration and to the crosswind integrated concentrations.
4. Most of the hydrocarbons in the plume are alkanes and therefore are classifiable as "non-reactive" in the time span of our plume measurements. Although there was some chemical loss of the

photochemically reactive hydrocarbon propene, there was no evidence of the formation of ozone in the plume as it moved downwind. In fact, the plume was generally deficient in ozone compared to the general airmass levels.

SECTION 3

EXPERIMENTAL PROCEDURES AND CONDITIONS

This research program was designed to be an integrated 3-dimensional air sampling study concentrating on light hydrocarbon concentrations around the test refinery and investigating possible related photochemical activity in the downwind area. The research was carried out using comprehensive ground-level data collected at a fixed laboratory site along with supplemental integrated bag samples from a number of sites in the neighboring countryside. The 3-dimensional aspect of the program was provided by an instrumented Cessna 336 aircraft. The aircraft collected bag samples for ground analysis and made other air quality measurements from on-board instrumentation.

Measurements

The research base facility was a 23-ft mobile trailer laboratory equipped for detailed gas chromatographic (GC) analysis of atmospheric hydrocarbon compounds and for continuous monitoring of ozone, NO, NO_2 CO, CH_4, and total hydrocarbons. The trailer laboratory also recorded the more important meteorological parameters: wind speed and direction, temperature, dew point, and solar radiation. The trailer station was kept at a single location during the field program but Teflon bag samples were collected at various locations around the refinery to supplement the plume assessment program. Table 1 lists the various ground measurements made at the trailer and the specific and instruments employed.

TABLE 1. GROUND MEASUREMENTS FOR LAWRENCEVILLE REFINERY STUDIES

Methane Total Hydrocarbon Carbon Monoxide	Beckmann 6800 Air Quality Gas Chromatograph
Individual C_2 - C_6 Hydrocarbons	Perkin-Elmer 900 Gas Chromatographs and Hewlett-Packard 3352 Data System
Ozone	Meloy OA 350
Nitrogen Oxides	Teco 14B (Moly Converter)
Wind Speed Wind Direction Dew Point Temperature Solar Radiation	Climet CI-60

Airborne sampling was conducted in a Cessna 336 Skymaster. It is a center line thrust, light twin-engined plane with an on-board instrumentation package capable of measuring up to 18 pollutant and flight variables. These are sequentially recorded on a Metrodata Systems 18-channel, four-track, 200-character/inch magnetic-tape cartridge recorder. Measured variables are recorded once each 0.4 second, equivalent to 16.8 meters of traverse when flying at 90 mph.

Table 2 lists the parameters continuously monitored in the aircraft.

TABLE 2. AIRCRAFT MEASUREMENTS

Gaseous and Particulate Measurements

- Condensation Nuclei (Environment One)
- Visual Range as calculated from B_{scat} (MRI integrating nephelometer modified to increase its sensitivity)
- Ozone (Bendix chemiluminescent)

Meteorological Measurements

- Temperature
- Relative Humidity

TABLE 2. AIRCRAFT MEASUREMENTS (con't.)

Navigational Measurements

VOR (Vector Angle)
DME (Distance Measure)
Altitude
Air Speed

A manifold was assembled in the rear portion of the cabin, which allowed rapid collection of air samples in Teflon bags. This consisted of a series of 1/4" SS lines with interspersed toggle valves such that, simply by opening the valve, ram air pressure would fill a 3-liter bag in about 15 seconds. These bags were analyzed for CO, NO_x, etc. at various points along the flight path.

Mapping of the flight path was accomplished through the use of continuously collected VOR and DME signals plus a visual record kept by the pilot and instrument operator aboard the aircraft.

Calibration

Calibration procedures were as follows:

Ozone Instruments - Complete calibration checks were performed twice weekly with a McMillan 1000 ozone generator. With this ozone source, concentrations in the range normally measured in ambient air (30-150 ppb) could be dependably produced. The generator itself was checked several times by the neutral buffered potassium iodide colorimetric method prior to taking it into the field. Instrument zero checks were made daily.

Nitrogen Oxides Instrument - Calibrated once at the beginning of the sampling period by making dilutions into Teflon bags from high-concentration (10 ppm) tank. Background suppression checks were made at least daily.

Methane, THC and Carbon Monoxide - Once a day calibration from tanks containing standards of known concentration.

Light Hydrocarbons - An internal standard (neo-hexane) of known concentration was included in each light hydrocarbon analysis.

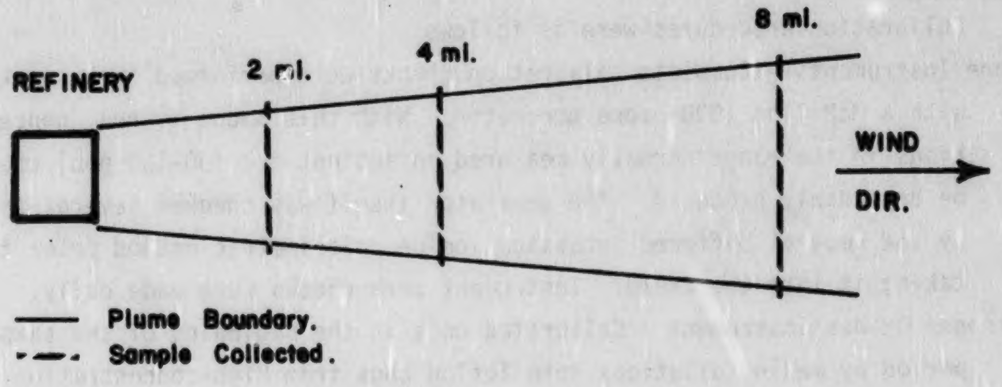
Light Scatter Instruments - Calibrated in our laboratory prior to use in the field.

Sampling Techniques

Ground level samples consisted of bag collections at various points outside the refinery fenceline and in the plume downwind of the refinery. The bags used were made of Teflon film. Contamination free, battery operated pumps were employed for filling these bags. In addition a continuous record of NO_x, O_3, CO, CH_4, and THC concentrations was obtained at the fixed trailer site. These latter measurements required no entrapment of air in plastic bags since the trailer was equipped with a stainless steel sampling stack and internal manifold that allowed direct sampling of the outside air.

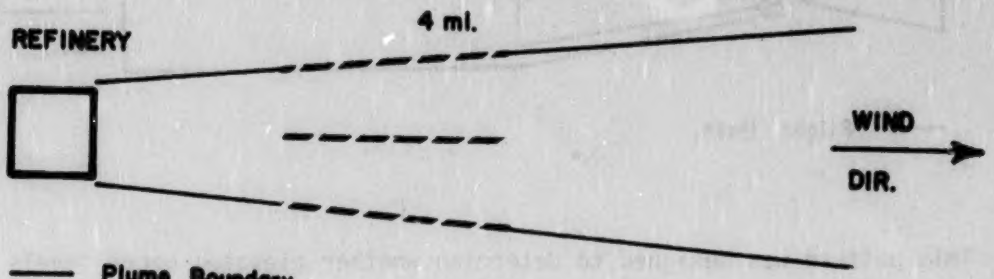
Aircraft flights were primarily designed to furnish information on plume composition and dimensions at various distances downwind of the refinery. On afternoons when meteorological conditions seemed favorable for oxidant production, the aircraft was used to survey areas where plume associated ozone build-up might be expected. The actual flight patterns are best classified into four types.

1) Sampling arcs perpendicular to downwind plume drift-



Plume width and vertical profile information was obtained in this manner. The latter was accomplished by flying across the plume at 500', 750', 1000', 1500', and 2000' above ground level. In addition a ground sample was collected directly under the aircraft. Generally we used a combination of two flights in close succession at distances shown in the diagram above. Thus over roughly a two hour period, bag samples were collected at ground level 500', 750', 1000', 1500', and 2000' at say four and eight miles downwind of the refinery.

2) Series of edge and middle plume samples collected parallel to downwind drift-

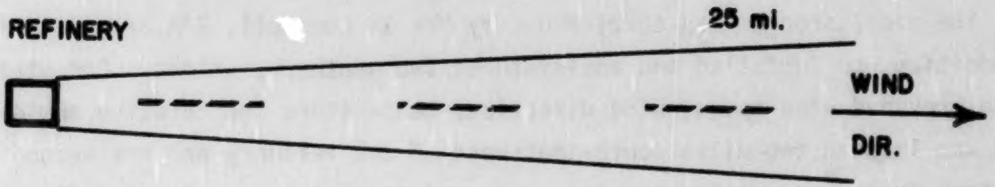


Plume Boundary.

Sample Collected.

This type of sampling was designed to show differences in hydrocarbon composition between various sections of the plume. Generally we worked within four miles of the refinery at 1000' above ground level. Ground samples were collected under the aircraft as well.

3) Sampling down the middle of the plume parallel to the wind direction

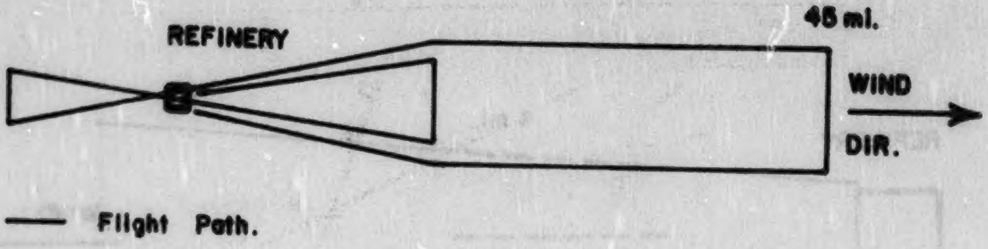


Plume Boundary.

Sample Collected.

The purpose here was to establish horizontal drift distance. Data and bags were collected as far as 25 miles downwind using this procedure. All sampling of this type was at 1000'.

4) Downwind ozone survey-



This pattern was designed to determine whether elevated ozone levels associated with the plume could be detected downwind of the refinery. As shown above, the flight path consisted of a short upwind leg and two downwind legs, the longest of which extended for approximately 50 miles.

Pilot ballon observations (pibal obs) were very helpful in vectoring the aircraft into the plume of the refinery, especially in the areas at considerable distance from the source. The pilot ballons were released each day at several points upwind and downwind of the refinery in order to determine the upper level wind speed and direction. These observations were also very useful in determining layers of wind shear and regions where the wind was significantly different from that recorded at ground-level.

The pibal program was carried out by Mr. Ev Quesnell, EPA meteorologist. In addition, he installed and administered two weather stations. One station, which provided wind speed, wind direction, temperature and relative humidity data was located two miles south-southwest of the refinery and the second station, including continuous wind speed and direction, was located five miles northeast of the refinery at the airport.

SECTION 4

RESULTS AND DISCUSSION

Our sampling program began in Lawrenceville on Thursday, June 13 and finished Monday, June 24. During this period, aircraft sampling was performed everyday except June 18. The weather was for the most part warm with overcast skies. Numerous thunderstorms occurred but they were quite localized and generally had little disrupting effect on aircraft operations.

The prevailing wind direction in this region of Illinois is from the southwest. Thus we sought a location for our permanent ground based sampling trailer to the northeast of the refinery. Figure 1 shows the trailer site - approximately 1-1/2 miles east-northeast of the refinery.

Refinery Description

The Texaco Plant in Lawrenceville, Illinois was selected for this study primarily because of its location - a large refinery in a region void of other industrial and urban emission sources. Lawrenceville is a town of about 6,000 population. Figure 1 shows the location of the refinery on the southeast edge of town.

Many of the present facilities of the refinery date back to the early 1950's when modernization of older facilities was commensed. In 1968 Texaco instituted an extensive construction program aimed at compliance with new Federal and State pollution regulations. At the time of our study, the CO boiler on the catalytic cracking unit was not yet in operation and the conversion from fixed to floating roofs on storage tanks was still in progress. This program is expected to be completed by late 1975. Table 3 lists refinery crude rates and estimated emissions during the study period.[3] Texaco personnel predict that CO emissions will become practically nil after start-up of the CO boiler and that hydrocarbon emissions will decrease by 68 percent when the conversion of floating roofs is complete.

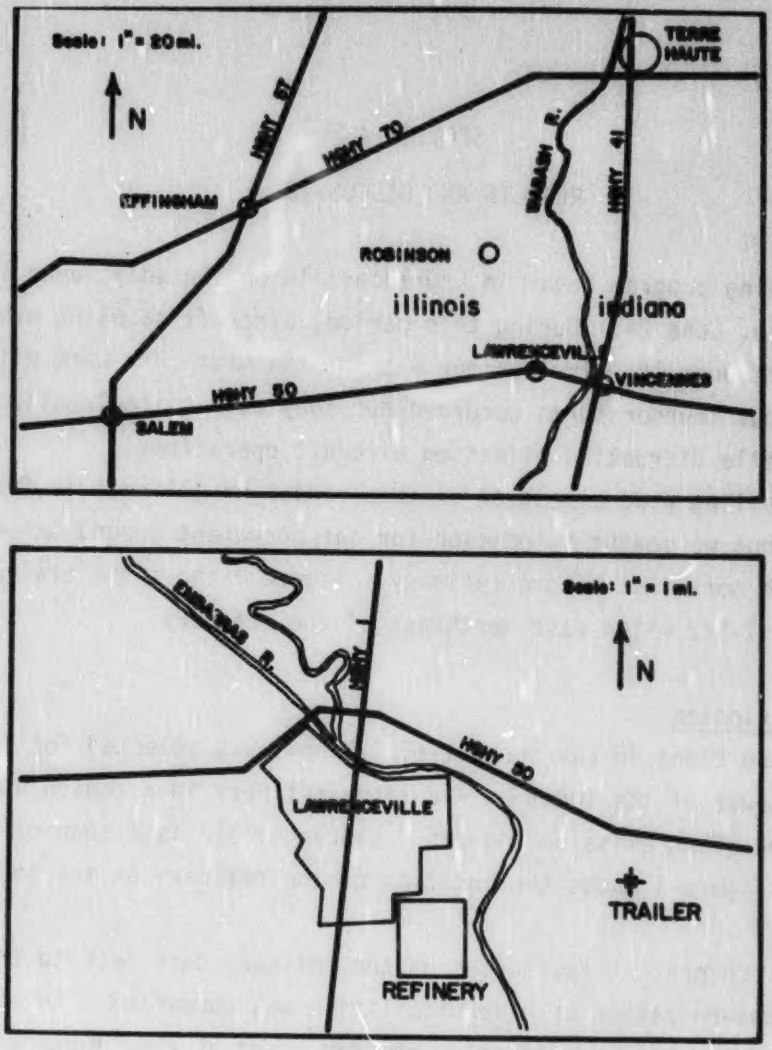

Scale: 1" = 20 mi.
N
TERRE HAUTE
HWY 57
HWY 70
WABASH R.
HWY 41
EFFINGHAM
ROBINSON
illinois
indiana
LAWRENCEVILLE
VINCENNES
HWY 50
SALEM
EMBARRAS R.
HWY 1
Scale: 1" = 1 mi.
N
HWY 50
LAWRENCEVILLE
TRAILER
REFINERY

Figure 1. Lawrenceville area maps

TABLE 3. CRUDE CAPACITY AND PLANT EMISSIONS FOR TEXACO REFINERY: JUNE 13-24, 1974

	TOTAL CRUDE RUNNING	TOTAL PLANT EMISSIONS (Lbs/day)			
	Bbl/day	HC	NO_x	CO	Particulates
6/13	87,000	25,931	8,906	605,328	3,857
6/14	87,000	25,933	8,577	609,740	3,772
6/15	82,000	25,903	8,632	611,965	3,565
6/16	85,000	25,953	9,621	616,416	3,785
6/17	83,000	25,926	8,142	616.416	3,431
6/18	82,000	25,896	8,156	578,715	3,544
6/19	79,000	25,899	8.719	576,497	3,687
6/20	73,000	25,899	7,112	411,754	3,594
6/21	72,000	25,787	7,181	573,366	3,051
6/22	60,000	25,731	5,935	595,939	2,955
6/23	80,000	25,769	6,572	586,910	2,998
6/24	81,000	25,797	7,993	566,594	3,053
AVERAGE	79,000	25,861	8,040	582,798	3,402

Gaseous Composition of the Refinery Plume

Figure 2 provides a graphical illustration of the general composition of the refinery plume. At some time during nearly every day, winds originating from the southwest quadrant (250-270°) carried the plume over the fixed ground monitoring site. As can be seen in Figure 2, substantial changes occurred in most measured parameters when this condition existed. Non-methane total hydrocarbon (NMTHC) levels increased from a background concentration of approximately .2 ppm to as high as 2 ppm. Carbon monoxide also increased although the amount of increase was somewhat variable. Large increases ($\sim$ 7 fold) occurred at the beginning and end of the period shown, while lower CO levels accompanied the plume on June 16.

Methane concentrations in and out of the plume are about the same, 1.7

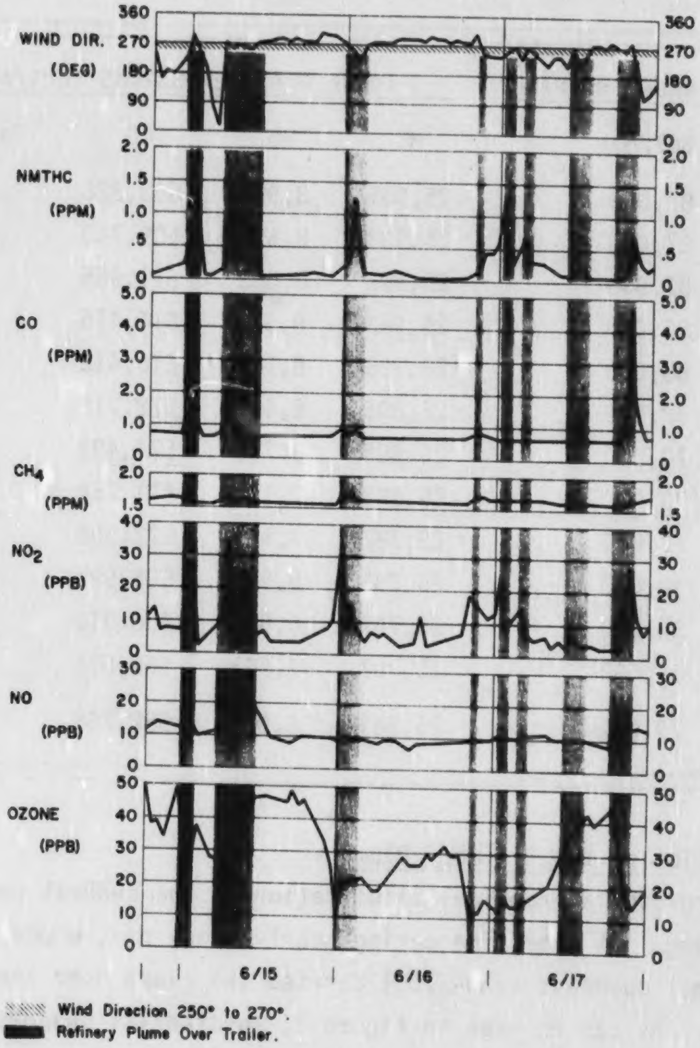


Figure 2. Ground measurements at trailer site on June 14-17.

and 1.6 ppm respectively. Therefore, methane does not appear to be a major component of refinery emissions. NO_x levels in the plume are about double those measured in background air. Ozone is included in the figure to illustrate its inverse relationship with oxides of nitrogen. It should be recalled that the data presented above was obtained at the trailer monitoring site approximately 1.5 miles from the refinery. This is probably the best measure of gross plume composition since the instruments which provided the data all monitor outside air directly with no entrapment in bags involved.

Plume Dimensions

Aircraft sampling provided the best method for monitoring plume dispersion. A combination of techniques were employed to locate and define the dimensions of the plume. Obvious starting points were determining wind direction both from our local weather stations and by observing visible refinery plume drift. The latter was especially helpful when working close-in to the refinery. Odor also provided a guide to plume location. However, it could only be used as a rough measure since quite often bags collected on the basis of odor alone were nearly void of hydrocarbons. Once the aircraft entered the general plume drift area, condensation nuclei counts were used to precisely define plume boundaries. A dramatic increase in CN levels always occurred as the aircraft entered the plume followed by a corresponding decrease as it exited from the plume. The integrating nephelometer could be used in the same way. A decrease in visual range was recorded in the plume as compared to areas outside the plume. When sampling close-in to the refinery, the ozone instrument provided another indicator of plume position. Often a decrease in ozone concentration would be observed when traversing the plume.

As an example of how these techniques were employed, the morning flight on June 23 will be analyzed in detail. This survey involved flying arcs perpendicular to the plume at two and eight miles downwind of the refinery. Bag samples were collected at 500', 750', 1000', 1500', and 2000' at both distances plus on the ground under the aircraft. Surface winds were from the north and constant so the general area of plume transport was easily determined. Several passes in a region eight miles south of the refinery served to pin-point plume width and location. This was achieved primarily through the use of the CN counter. Sample runs across the plume were then made at the altitudes mentioned above. Figure 3 shows a processed account of what the flight operator sees on board the aircraft during a sampling arc.

The time span covered in this particular data record (1000' traverse) is about three minutes. As the aircraft approached the plume, a CN count (third column from the right) of about 6800 was recorded. At approximately 9:22, the CN level began to rise and quickly exceeded 16000. Collection of bag sample A-3 was started at 9:22:24 and stopped 33 seconds later at 9:22:57. These points are marked in the figure. Twenty seconds later the CN levels returned to approximately 7000 as the plane emerged from the plume. At this distance no noticeable change occurred in the ozone level; however, there is a definite decrease in visual range as measured by the integrating nephelometer (fifth column from the right).

Figures 4 and 5 provide time plots of CN count, visual range and ozone concentration for all passes through the plume at 2 and 8 miles. Information obtained from bag samples collected in the plume is presented in Table 4. A combination of information provided by the CN counter, nephelometer and individual hydrocarbon analyses was used as the basis for assigning crosswind plume dimensions. From the data just presented for the morning of June 23 it is clear that the upper limit of hydrocarbon dispersion was somewhat less than 2000'. Both at 2 miles and 8 miles there is a dramatic drop in hydrocarbon concentration between 1500' and 2000' (Table 4). Examination of the vertical temperature profile in this region shows a change of slope (warming trend) at about 1800' which probably coincides with the upper limit of plume dispersion. The CN data and visual distance readings support an upper boundary of less than 2000' at 8 miles since no instrument response was observed. However it can be seen in Figure 5 that a rise in CN was recorded at 2000' when 2 miles downwind. This probably results from hot stack gases penetrating through the top of the mixing layer.

Horizontal cross-sectional dimensions were best determined from CN count. On June 23 elevated condensation nuclei levels were recorded for approximately 90 seconds when traversing the plume at 1000-1500' two miles from the refinery. At an aircraft sampling speed of 90 mph, a plume width of 90 seconds translates into 2.3 miles. Thus at 2 miles downwind of the refinery our measurements reveal a plume ceiling of about 1800' and a horizontal width of 2.3 miles.

```
                    ATMOSPHERIC MEASUREMENTS

PROJECT          --5 CITIES LIGHT HYDROCARBON STUDY
SITE OF SAMPLING--LAWRENCEVILLE, ILLINOIS
DATE OF SAMPLING--23 JUNE 74      MORNING FLIGHT 02                PROGRAM VERSION 74.240

 5 SCAN AVERAGES BEGINNING  9:21 CDT     23 JUN 74

MIDPOINT ONE  VCR  IAS  1COX 100Y %ALT TEMP REL  BSCP RFPH  UB  10CN L CN # TU
  TIME   CHMI DEG. MPH  *NMI *NMI 10FT C*10 HUMU -6/M  KM.  PPB /ML. *100 AVG.
 9:21:45 1984   55  107 1623 1145  110  142   52    9  123   21  664  342    5
 9:21:48 1985   55  109 1627 1144  109  142   52    8  126   22  670  383    4
 9:21:50 2003   55  109 1629 1142  108  142   52    7  129   23  657  382    4
 9:21:52 2006   55  112 1633 1142  107  143   53    8  128   23  650  381    5
 9:21:54 2008   55  113 1634 1141  105  142   53    8  125   22  690  381    5
 9:21:56 2008   55  112 1641 1139  105  142   53    8  125   20  674  383    5
 9:21:59 2002   55  113 1645 1136  104  143   53    8  125   21  746  387    5
 9:22: 1 2015   55  116 1653 1135  103  142   53    8  125   21  825  392    4
 9:22: 3 2022   56  119 1660 1137  103  143   53    9  124   20  890  395    5
 9:22: 5 2030   56  116 1673 1137  103  142   53    9  122   21 1015  401    4
 9:22: 8 2036   56  118 1676 1137  102  143   53   10  119   23 1380  414    5
 9:22:10 2044   56  117 1683 1140  102  142   52    9  121   22 1560  419    5
 9:22:12 2046   56  117 1689 1146  102  143   52    9  124   23 1618  421    5
 9:22:15 2055   56  115 1692 1147  101  143   51    8  125   24 1525  418    4
 9:22:17 2056   56  112 1694 1147  102  142   51    9  122   23 1274  411    5

EVENT NUMBER  98 OCCURRED AT  9:22:24

BAG START/STOP AT  9:22:24
 9:22:19 2054   55  114 1698 1147  102  143   52    9  121   23 1002  400    5
 9:22:21 2065   56  110 1700 1149  102  143   52   10  117   21  922  396    4
 9:22:24 2072   56  105 1707 1148  102  142   51   15  104   19  976  399    5
 9:22:26 2070   56  108 1719 1146  103  143   52   16  100   20 1170  407    5
 9:22:28 2078   56  114 1724 1146  104  142   52   22   86   19 1332  412    4
 9:22:30 2084   57  111 1726 1147  104  143   52   31   72   20 1488  417    5
 9:22:32 2088   57  108 1737 1148  105  143   53   35   67   19 1738  424    5
 9:22:35 2093   56  105 1742 1147  105  142   52   38   64   20 1900  428    4
 9:22:37 2098   56  107 1746 1145  106  142   52   41   61   20 2074  432    5
 9:22:39 2100   57  105 1749 1148  106  142   53   40   62   21 2198  434    5
 9:22:41 2108   57  107 1756 1148  106  142   52   43   59   23 2256  435    5
 9:22:43 2110   57  106 1761 1145  105  142   52   44   58   22 2256  435    5
 9:22:46 2116   57  105 1766 1143  105  142   52   43   59   22 2270  436    5
 9:22:48 2114   57  107 1770 1146  104  141   52   35   67   22 2228  435    5

EVENT NUMBER  98 OCCURRED AT  9:22:57

BAG START/STOP AT  9:22:57
 9:22:50 2122   57  107 1774 1146  103  142   52   22   86   21 2024  431    5
 9:22:52 2122   57  109 1780 1143  103  142   52   15  102   22 1650  422    5
 9:22:54 2125   57  107 1784 1143  103  142   53   13  110   21 1187  407    4
 9:22:57 2130   58  110 1786 1138  103  142   53   11  113   21  957  398    3
 9:22:59 2134   58  108 1794 1114  104  142   53   11  115   21 1164  407    5
 9:23: 1 2130   58  107 1804 1113  106  142   53   11  115   21 1874  427    5
 9:23: 3 2136   59  103 1808 1106  106  142   54   11  115   21 2476  439    5
 9:23: 5 2144   59  106 1819 1098  108  141   54   11  115   21 2648  442    5
 9:23: 7 2146   59  104 1831 1095  108  142   54   11  115   20 2518  440    5
 9:23: 9 2152   59  103 1833 1096  108  142   54   11  115   21 2264  435    5
 9:23:11 2150   59  101 1835 1093  108  141   54   11  115   21 2010  430    5
 9:23:13 2138   59   99 1833 1093  108  142   54   11  115   21 1680  423    5
 9:23:16 2148   60   97 1831 1089  108  141   54   11  115   21 1352  413    5
 9:23:18 2140   59   98 1836 1073  108  141   54   11  115   21 1120  405    5
 9:23:20 2146   59  100 1840 1069  108  142   54   11  115   22  908  396    5
 9:23:22 2160   60  101 1847 1057  109  141   53   11  115   22  794  390    5
 9:23:24 2160   60  104 1852 1053  110  141   53   10  119   22  722  386    4
 9:23:27 2158   61  107 1847 1059  111  141   53    9  123   22  690  384    5
 9:23:29 2150   59  106 1841 1066  113  140   53   10  119   23  684  384    5
 9:23:31 2143   58  102 1842 1070  115  140   53   11  113   21  695  384    4
 9:23:33 2150   60  102 1844 1080  118  140   53   12  112   22  700  385    5
 9:23:36 2160   60  104 1849 1084  122  140   53   12  111   21  700  385    4
 9:23:38 2168   60  105 1859 1082  125  140   53   13  108   22  700  385    4
 9:23:41 2168   60  105 1864 1083  127  139   53   13  108   22  696  384    5
 9:23:43 2172   59  108 1865 1089  129  140   53   13  106   22  708  385    5
 9:23:45 2178   59  111 1868 1094  131  139   53   13  108   21  718  386    5
```

BAG A-3

Figure 8. [illegible] height, visual range, and ozone concentration [illegible] during traverse in the [illegible]

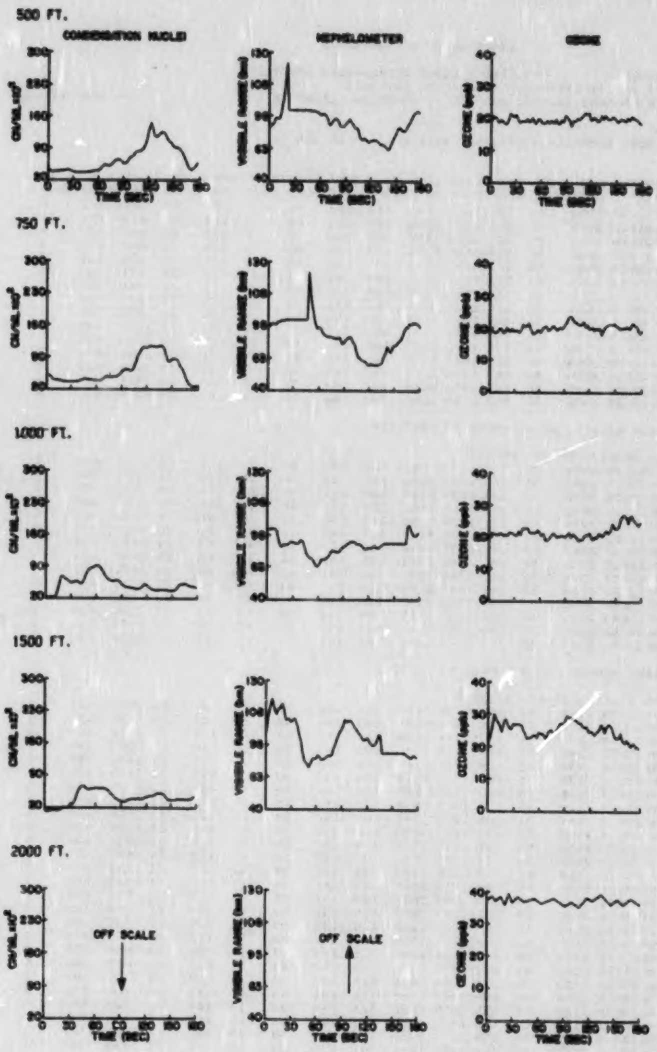


Figure 4. Plots of time vs consensation nuclei, visual range, and ozone concentration while traversing the plume at 8 miles.

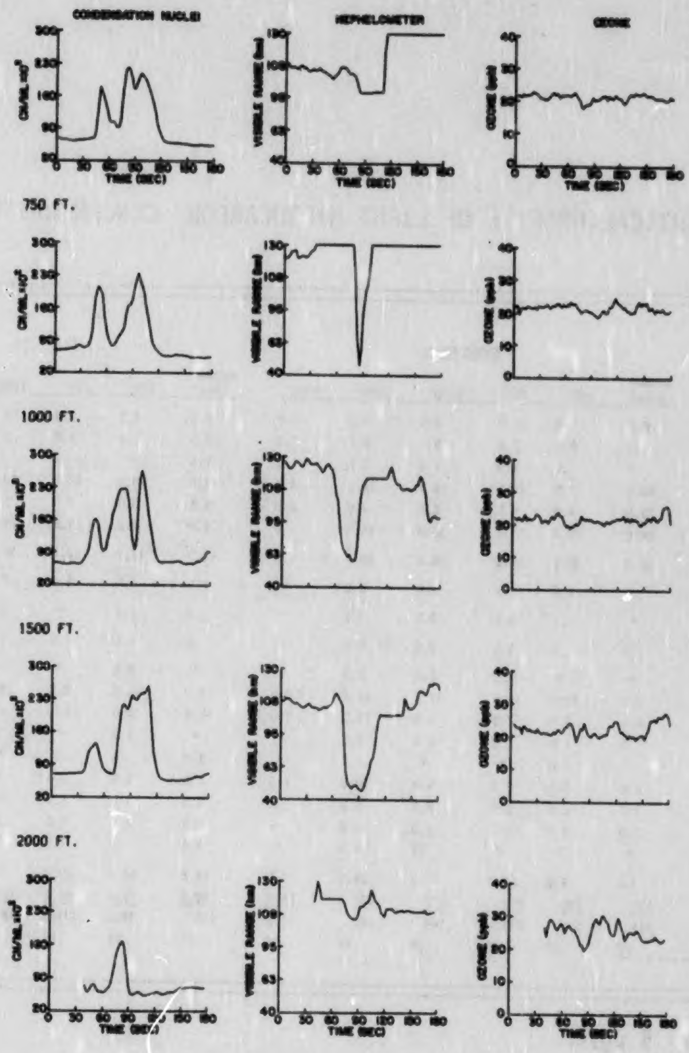


Figure 5. Plots of time vs condensation nuclei, visual range and ozone concentration while crossing the plume at 2 miles.

TABLE 4. VERTICAL PROFILE OF LIGHT HYDROCARBON CONCENTRATIONS ($\mu g/m^3$)

	Eight Miles						Ten Miles					
	Ground Level	500'	750'	1000'	1500'	2000'	Ground Level	500'	750'	1000'	1500'	2000'
Ethane	8.5	7.0	11.0	9.5	9.0	3.5	8.5	8.5	9.0	12.5	13.0	5.0
Ethylene	4.0	2.5	7.5	9.0	9.0	7.0	2.0	4.0	4.0	5.5	4.0	3.0
Acetylene	.5	.5	1.0	1.0	1.0	.5	1.0	*	.5	*	1.0	*
Propane	23.0	17.5	29.5	16.5	18.0	3.0	17.0	18.0	22.5	50.5	41.5	4.0
Propene	3.5	4.0	6.0	2.0	3.0	2.0	5.5	3.0	3.5	5.0	5.0	1.5
1-Butane	54.0	39.5	95.5	38.0	54.5	1.0	9.0	8.0	11.5	29.5	28.5	2.5
n-Butane	30.0	30.5	52.5	26.5	68.5	5.0	19.0	17.5	23.0	39.0	50.0	9.5
neo-Pentane 1-Butene	.5	1.0	4.5	3.0	2.5	*	1.5	1.5	1.0	2.0	1.0	*
1-Butene	*	.5	3.5	3.5	4.5	*	1.0	2.0	*	2.0	1.5	*
t-2-Butene Propyne	.5	.5	3.5	3.5	5.0	*	.5	1.5	1.5	1.0	1.0	*
c-2-Butene	*	*	2.5	1.5	3.5	*	*	2.0	*	*	*	*
1-Pentane	9.0	19.0	19.5	17.0	47.5	10.0	13.0	11.0	8.5	16.5	37.0	7.5
n-Pentane	4.0	7.5	7.0	6.0	15.5	2.0	11.0	6.0	6.5	6.5	12.0	2.0
Cyclopentane	1.0	1.0	2.0	1.0	2.5	*	*	1.0	*	1.5	1.0	.5
1-Pentene	.5	1.0	*	*	3.5	*	1.0	.5	*	1.0	1.0	*
1-Hexane	2.0	3.5	4.0	4.0	10.0	1.5	3.5	3.5	3.5	3.0	5.5	2.5
3-Methylpentane	1.0	2.0	2.0	2.0	6.5	.5	2.0	1.5	1.5	2.0	4.5	1.0
n-Hexane	3.0	3.5	1.5	2.0	3.5	*	6.5	1.0	1.0	3.0	2.0	.5
Cyclohexane	*	*	*	.5	1.5	*	2.0	.5	1.0	*	*	*
Total Olefins	9.0	9.0	24.0	20.5	29.5	9.5	11.5	14.5	10.5	16.5	14.5	4.5
Total Paraffins	136	131	225	123	237	26.5	92.5	75.5	88.5	164	196	36.0
Total $\mu g/m^3$	145	140	249	144	267	36.0	104	90.0	99.0	181	210	40.5
Total ppm C	.22	.21	.38	.22	.41	.06	.16	.13	.15	.28	.32	.06

* less than .5 $\mu g/m^3$

One question that might arise at this point is: How legitimate is it to assign plume width based on condensation nuclei count? We find that the plume width determined from CN counts agrees closely with that expected based on physical dimensions of the refinery. The Lawrenceville plant is rectangular in shape with the long axis in an east-west direction. Thus the greatest plume width should be measured when sampling north or south of the refinery. As illustrated in Figure 6, this is what was found. Based on CN count the plume was about twice as wide to the north and south as it was directly to the east of the plant. Furthermore, sampling traverses northeast of the refinery showed a plume width intermediate between that of east and north.

Good quantitative agreement exists between plume width at short distances downwind and the size of the source area. At 90 mph the plane will cover about 1.5 miles/min. A plume width of 35 seconds to the east of the refinery equals a distance of .9 miles. This is the same as the north-south dimensions of the plant. Likewise, a time of 75 seconds recorded to the north corresponds to 1.9 miles in distance which again is nearly the same as the distance between the east and west boundaries of the plant.

Downwind Plume Drift

We found elevated hydrocarbon levels as far as 24 miles downwind. Data gathered on the afternoon of June 19 is shown in Table 5. These are aircraft samples collected at 1000', 16 to 24 miles downwind of the refinery. Especially noteworthy here is the high concentration measured at 24 miles. During the same flight a sample was collected at about this same distance, but out of the plume, and thus can serve as a background comparison. Obviously the 16 and 22 mile bags were not in the main stream of the plume.

It is extremely difficult to draw conclusions and make generalizations as to the absolute dilution of hydrocarbons with distance. This is highly dependant on the prevailing meteorological conditions. Certainly wind speed and wind shear plus mixing depth will be important factors. In addition the aircraft sampling procedure used to monitor hydrocarbon dilution vs. distance is tricky. Ideally, one should fly parallel with the plume and down its middle collecting samples at increasing distances downwind. This is difficult because it requires a constant wind flow and that the aircraft heading selected be absolutely in line with the wind direction. The data provided in Table 7 is

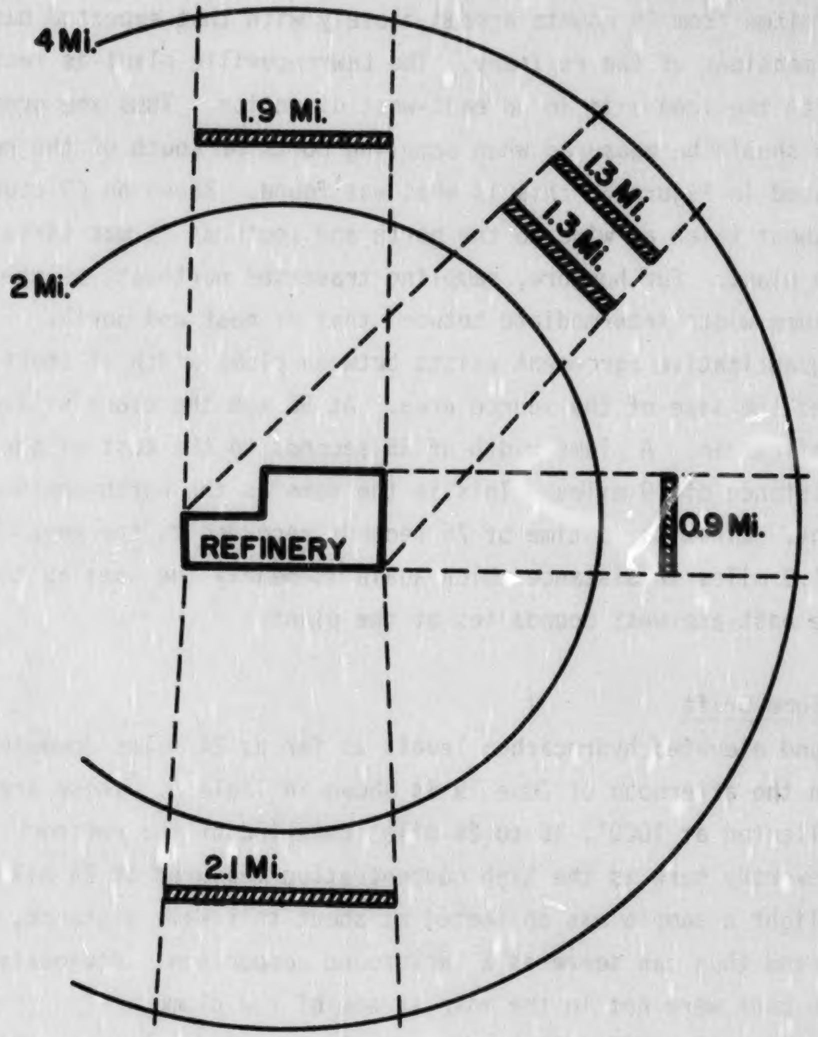

4 Mi.
1.9 Mi.
1.3 Mi.
1.3 Mi.
2 Mi.
REFINERY
0.9 Mi.
2.1 Mi.

Figure 6. Plume width (based on condensation nuclei levels) in relation to approximate dimensions of the refinery.

TABLE 5. LIGHT HYDROCARBON CONCENTRATIONS$^+$ DOWNWIND OF REFINERY ON JUNE 19

	16 miles	19 miles	22 miles	24 miles	18 mile Background
Ethane	6.0	10.0	10.5	6.5	8.0
Ethylene	5.5	6.5	6.0	7.0	8.0
Acetylene	*	.5	*	1.0	.5
Propane	7.5	21.0	17.5	28.0	6.5
Propene	1.5	2.5	2.5	2.5	1.0
i-Butane	5.5	15.5	8.5	45.5	2.0
n-Butane	16.0	47.0	16.5	190	5.5
neo-Pentane 1-Butene	*	4.0	1.0	2.5	*
i-Butene	.5	3.5	2.0	2.5	.5
t-2-Butene Propyne	*	4.0	1.5	6.0	*
c-2-Butene	*	4.5	1.5	5.0	*
i-Pentane	11.5	31.5	10.5	126	4.0
n-Pentane	5.0	14.0	5.0	49.0	2.0
Cyclopentane	*	3.0	.5	6.0	*
1-Pentene	.5	1.5	*	3.0	*
i-Hexane	2.0	9.5	2.5	34.5	1.0
3-Methylpentane	2.5	3.5	1.5	18.5	*
n-Hexane	2.0	3.5	1.5	18.5	.5
Cyclohexane	*	1.5	.5	3.0	.5
Total $\mu g/m^3$	68	187	895	541	39.5
Total ppmC	.10	.29	.14	.83	.06

$^+\mu g/m^3$

*less than .5 $\mu g/m^3$

our best result from this type of flight. It shows that under the conditions at the time (southwest wind at 11 mph) there occurred about a 6% decrease in hydrocarbon concentration/mile. The fact that the ratio of light hydrocarbons (C_3 - C_4) to the heavier (C_5- C_6) is fairly constant provides some assurance that dilution was what we were measuring and not differences within the plume itself.

TABLE 6. HYDROCARBON DILUTION VS. DISTANCE FROM REFINERY

Distance from Refinery	Total[+] Concentration	C_3-C_4/C_5-C_6	Relative Concentration
1/2 mi.	158	3.5	1
4	113	3.4	.72
8	81	3.1	.51

[+] Total μg/m^3 of Propane, i-Butane, n-Butane, i-Pentane, n-Pentane, i-Hexane and n-Hexane.

The aircraft hydrocarbon sampling data obtained downwind of Lawrenceville refinery have been analyzed and compared with meteorological diffusion calculations applicable to the same general situations. The aircraft sampling data have been classified in terms of whether the samples apply to the center-line average concentrations as a function of distance downwind from the refinery, or to the crosswind integrated concentration at different distances from the refinery. Table 7 shows the available crosswind integrated hydrocarbon concentrations along the plume center line as a function of downwind distance. Each table shows the date of the flight, an indication of whether the flight was an afternoon or a morning flight, the distance at which the sample collection was obtained, the altitude of the aircraft above ground, the average wind speed during the sampling period as indicated by the wind instruments maintained at the trailer station, and the concentration in micrograms per cubic meter obtained by GC analysis of the bag sample.

In the following diffusion study the aircraft bag-sampling data have been adjusted to reflect an average hydrocarbon background concentration of

35 μg/m^3. The concentrations shown in Tables 7 and 8 are the observed values, not the adjusted numbers. This 35 μg/m^3 background concentration was obtained from the several samples made during the test period in directions not affected by the refinery plume or major urban areas. There are variations in this background level estimate for the various daily conditions. It was not possible to provide an identifiable background sample for each individual test day so one single sample value has been used to correct all of the concentration data.

Figure 7 shows the analysis of the crosswind integrated concentration data as obtained downwind from the Lawrenceville refinery. Four sampling flights were available for analysis, two of which provided extremely useful data and two provided only qualitative results. The most useful flight data were obtained on June 20 in the afternoon and on June 24 in the morning. Note that in Table 7 these are the two periods with a significant number of data points. In the case of June 20, the concentration data extended from a distance of 5 miles out to 20 miles with crosswind integrated concentration samples being obtained at distances of 5, 10, 15 and 20 miles from the refinery. One June 24, crosswind integrated concentration data were obtained at distances of 5, 10, 20 and 25 miles from the refinery. It should be noted that the y axis of Figure 7 is the background-corrected concentration times the wind speed at the particular time of observation. This combination of variables tends to smooth out some of the variations from day to day that are caused merely by the dilution proportional to the wind speed. Figure 7 also shows two theoretically calculated dispersion curves, labeled A and B. Curve A is a dispersion calculation made to approximate type C or light instability conditions while curve B is calculated to approximate an instability condition which is somewhat more unstable than type C. More will be said about these two calculated curves later in this discussion. In general, it appears that the change in concentration of the crosswind integrated concentration for both the tests, June 24 and June 20, are reasonably well approximated as functions of distance by Curve B.

Figure 8 is a presentation of the data obtained during the five tests when samples were taken to measure the downwind change in concentration along the center line of the refinery plume. As with Figure 7, the y axis of Figure 8 is a function of the corrected concentration times the wind speed and the x

TABLE 7. CROSSWIND HYDROCARBON DATA

Date	Distance (Miles)	Altitude (Feet)	$\bar{u}$ (°/mph)	Concentration ($\mu g/m^3$)
6/19 PM	16	1000	210/12	68
	19	1000	210/12	182
	22	1000	210/12	104
	24	1000	210/12	541
	25	1500	210/12	113
6/20 AM	5	500	7	156
	10	500	7	118
	15	500	7	154
	20	500	7	75
	20	500	7	93
PM	10	1000	10	72
	16	1000	10	41
6/24 AM	5	1000	10	221
	10	1000	10	134
	20	1000	10	(121)
	25	1000	10	93
	25	1000	10	82

TABLE 8. PLUME CENTERLINE HYDROCARBON DATA

Date	Distance (Miles)	Altitude (Feet)	$\overline{u}$ (°/mph)	Concentration (μg/m^3)
6/13 PM	2-4	1000	3	162
	16-20	1000	3	68
	26-30	1000	3	62
6/15	2	1000	14	51
	34	1000	14	34
6/21 PM	1-2	1000	15	128
	4-5	1000	10	173
	9-10	1000	6	228
6/23 PM	4	1000	18	66
	12	1000	18	37
6/24 PM	2	1000	15	198
	8	1000	15	78
	16	1000	15	50
	28	1000	15	60

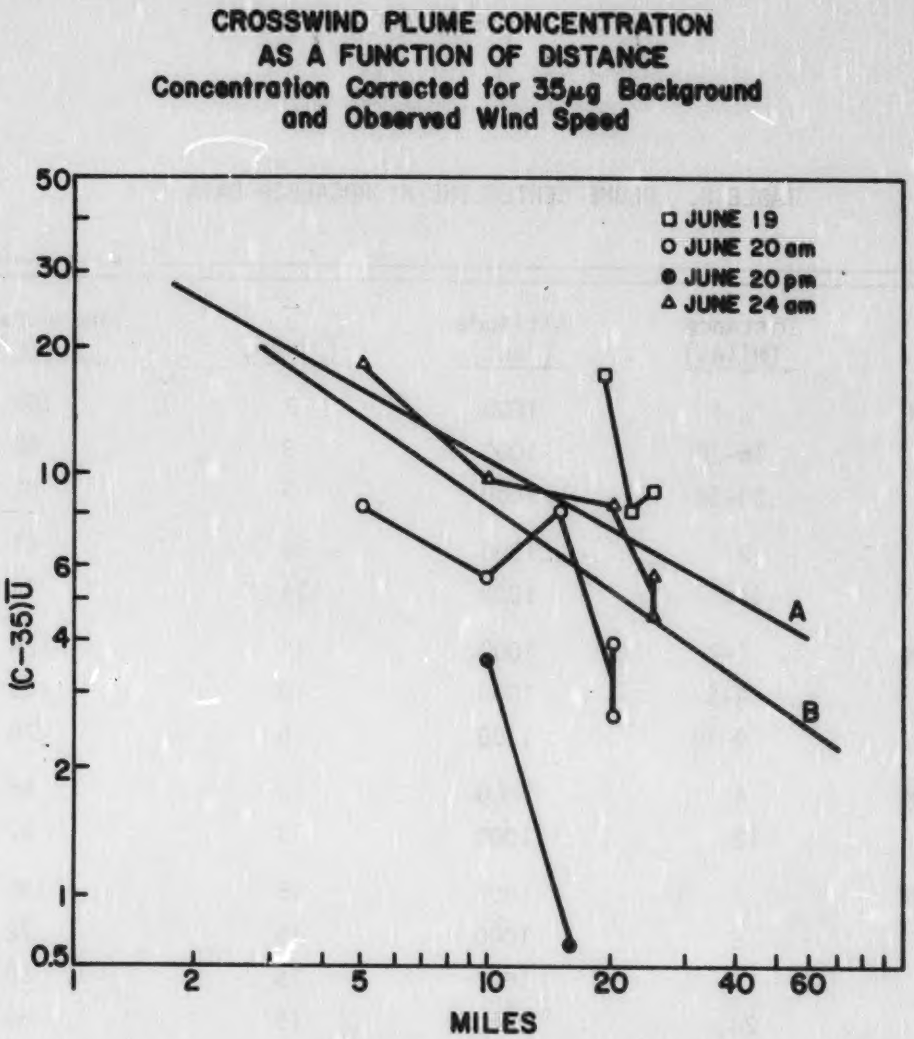


Figure 7. Crosswind plume light hydrocarbon concentration as a function of distance.

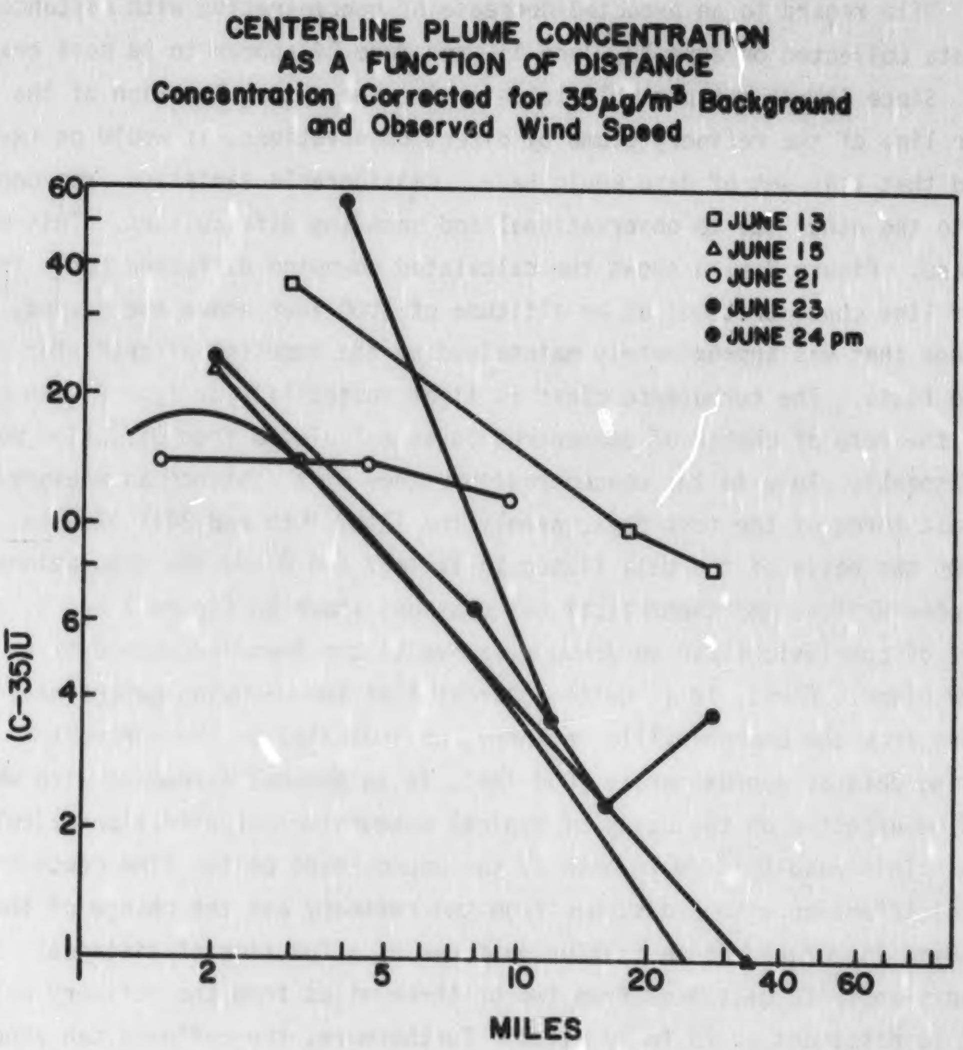


Figure 8. Centerline plume light hydrocarbon concentration as a function of distance.

axis is distance in miles from the refinery. There is a lot of variation from test to test and the differences from one day to the next are considerable. With regard to an expected decrease of concentration with distance, the data collected on June 13, June 15, and June 24 appear to be most reasonable. Since it was not possible to determine the actual location of the center line of the refinery plume by direct observations, it would be expected that this set of data would have a considerable variation from one test to the other due to observational and sampling difficulties. This was the case. Figure 8 also shows the calculated downwind diffusion curve for center line concentrations at an altitude of 1000 feet above the ground, the altitude that was approximately maintained by the sampling aircraft for most of the tests. The turbulence class is light instability or Type C. In general, the rate of change of concentration as calculated from diffusion models is reasonably close to the concentration change with distance as measured on at least three of the test days, namely the 13th, 15th and 24th of June.

On the basis of the data listed in Table 7 and 8 and the tabulations of both observations and theoretical calculations shown in Figure 7 and 8, a number of conclusions can be drawn relative to the downwind nature of the refinery plume. First, it is quite apparent that the downwind concentration pattern from the Lawrenceville refinery, as indicated by the aircraft sampling data at approximately 1000 feet, is in general agreement with what would be expected on the basis of typical meteorological diffusion calculations. This result is shown both by the approximate center line concentration distribution with a distance from the refinery and the change of the crosswind integrated concentration patterns as a function of distance. These comments apply to distances from two or three miles from the refinery out at least to distances of 25 to 30 miles. Furthermore, the refinery can apparently be considered as a point source of pollutant hydrocarbons at these distances. Turbulence characteristics of the air masses dispersing the refinery plume can apparently be described as having light to moderate instability or turbulence causing the pollutant dispersion. In diffusion modeling terminology, this situation is known as "Type C." The variations towards a more unstable condition are in the direction of a type B stability, but the instability is not as intense as is normally described for mid-day, summer conditions such as were encountered in this program. In crosswind plume data the vertical turbulence coefficients are probably two or three times the turbulence values for type C stability but they still are significantly less than is usually indicated for a type B stability. These remarks in particular refer to the results of the crosswind integrated diffusion calculations, shown on Figure 7. The center line concentration distributions are probably more readily described by type C stability. However, the difficulty in making a truly representative center line co centration measurement with aircraft sampling would probably tend to indicate a more stable plume than was actually the case. Thus, there is probably no valid reason to assume that the plume is not characterized by turbulence that is the same as indicated by the crosswind data.

The aircraft samples indicate that on different days there were apparently significant differences in the overall concentration levels in the plume. Changes in total concentration levels would be expected on the basis of differences in windspeed and stability. In the data used to plot Figure 7 and 8 an initial correction for changes in windspeed was made on the basis of the recorded wind at the ground base trailer location. This is obviously only a first approximation because the plume at 1000 feet would be influenced by a significantly different windspeed, probably considerably higher. The concentration changes from day to day as observed in the Lawrenceville data also would reflect day to day changes in the emissions from the source; however, these are probably a much smaller influence on the observed concentrations than are the changes and impact of different meteorological conditions. In any attempt to reproduce the downwind ground-level concentration from a given refinery or other point source, it would obviously be necessary to include a very good approximation of the wind field because of its influence not only on the direct dilution of the pollutant plume but also its effect on the plume rise from the source itself.

As indicated above, the aircraft sampling shows the Lawrenceville refinery is readily detectable in terms of hydrocarbon measurements for distances of more than 25 miles and that the nature of the transport plume is generally predictable on the basis of meteorological diffusion principles.

Plume Chemistry

The chemical composition of the refinery plume has been mentioned in most of the preceding sections. Of prime interest in terms of atmospheric chemistry are the relationships between hydrocarbons, oxides of nitrogen and ozone. It was pointed out earlier that methane was not an important component of the plume, however, other members of the alkane family dominate the non-methane hydrocarbon composition. Figure 9 shows a chromatogram typical of those encountered in the plume. Qualitatively, it is obvious that the saturated hydrocarbons, propane, i-butane, n-butane, i-pentane and n-pentane, are most prevalent. Also noticeable is the very small amount of acetylene present. In general, unsaturated compounds comprise only about 10% of the total. This value decreases to less than 1% in samples collected immediately adjacent to the tank storage area. This data, of course, is only representative of the lower molecular weight hydrocarbons since our individual hydrocarbon analysis covered compounds of six carbon atoms and less. The question of what percentage this is of the total can be answered to some extent by comparing the light hydrocarbon total with the non-methane total hydrocarbon value for a number of samples. The two measurements can vary by as much as a factor of two, but at the highest concentrations, where both types of analysis are most accurate, the difference is normally about 20%. If the latter figure is used, the light hydrocarbon totals we report represent approximately 80% of the total non-methane hydrocarbon content of the plume.

When sampling within two miles of the refinery, differences were observed in hydrocarbon composition within the plume. For example, on the afternoon of June 16 two ground samples were collected to the southeast of the refinery. The two collection points were within the plume but separated by about one mile. Analysis of these samples showed considerable variation in the hydrocarbon composition. The bag collected on the southern edge (tank side) of the plume contained a larger proportion of hydrocarbons in the C_5 and C_6 molecular weight range than did the one collected on the northern-most side of the plume. This is illustrated in Table 9. On other occasions a similar behavior was observed. Table 9 also shows results from aircraft samples collected to the northwest of the refinery on June 21. Again on this afternoon, one side of the plume was richer in C_5 and C_6 hydrocarbons than the other. Figure 10 summarizes this data. It can be seen that the side of the plume containing the

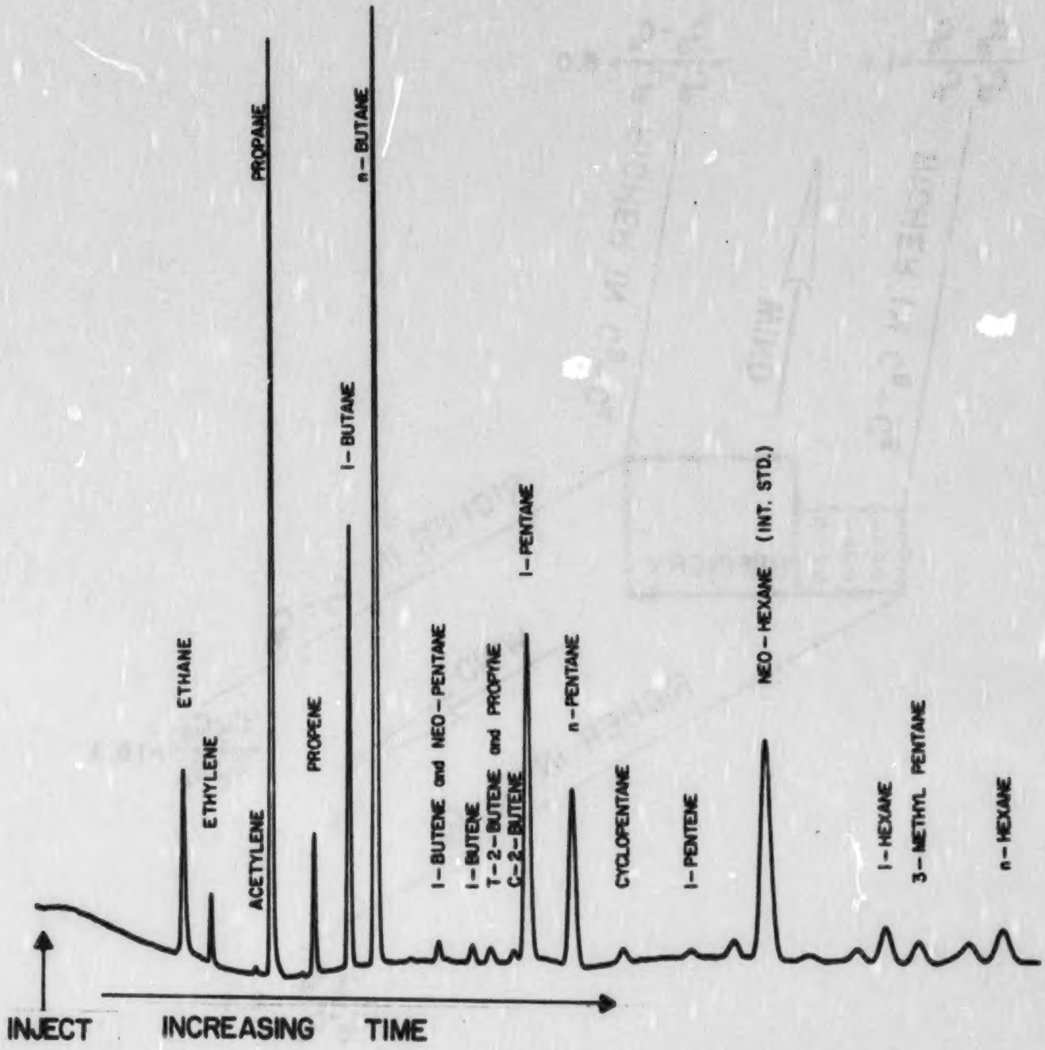
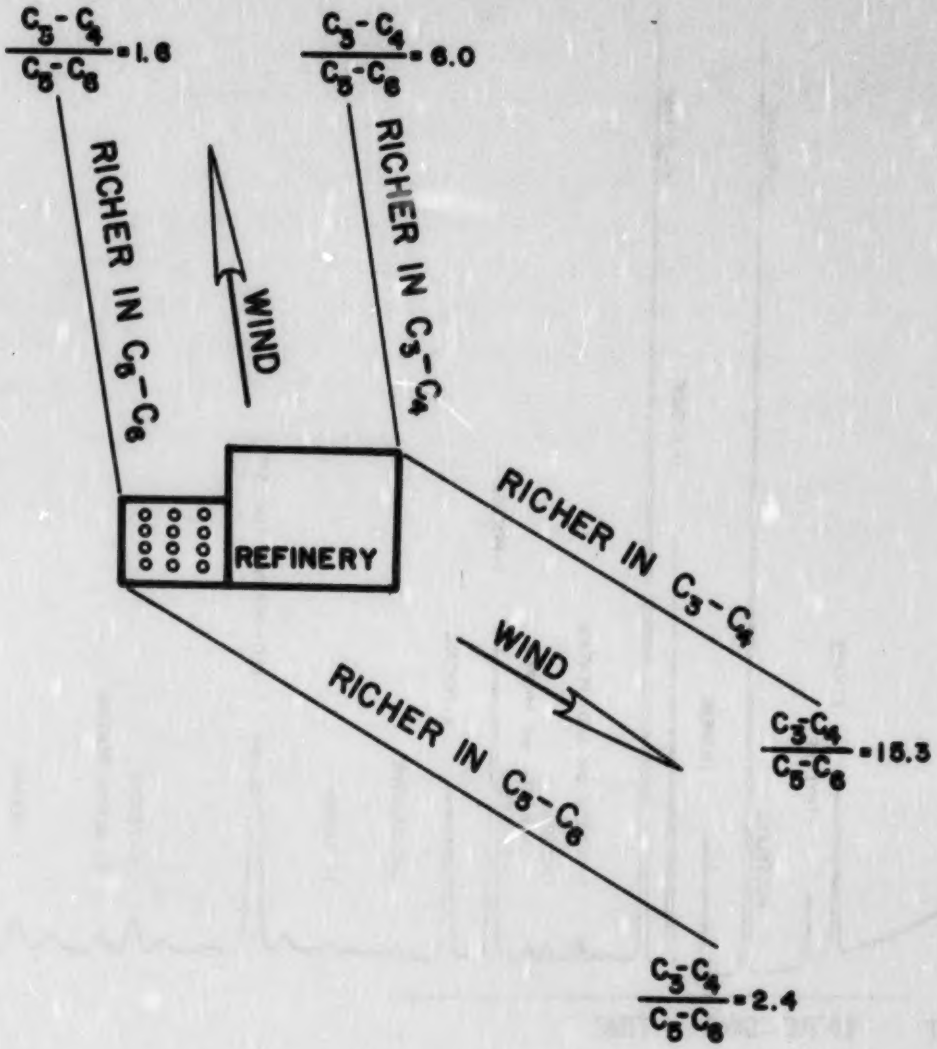


Figure 9. Light hydrocarbon chromatogram typical of the plume.



$\frac{C_3-C_4}{C_5-C_6}=1.6$
$\frac{C_3-C_4}{C_5-C_6}=6.0$
RICHER IN C_5-C_6
WIND
RICHER IN C_3-C_4
REFINERY
RICHER IN C_3-C_4
WIND
RICHER IN C_5-C_6
$\frac{C_3-C_4}{C_5-C_6}=15.3$
$\frac{C_3-C_4}{C_5-C_6}=2.4$

Figure 10. Variations in hydrocarbon composition within the plume.

higher proportion of C_5 and C_6 hydrocarbons can be traced back to the western edge of the plant. The major tank storage area is located on this edge of the refinery and as shown in Table 9 the hydrocarbon ratio determined from ground samples collected just outside the fenceline enclosing this tank area agrees quite closely with the ratio measured downwind on that side of the plume.

The disappearance of olefinic hydrocarbons has been used as a measure of chemical aging within an air mass.[5] Application of this principle to the refinery plume is possible if olefin decrease due to dilution can be clearly defined or eliminated as a variable. A hydrocarbon dilution of approximately 6% per mile was established for the plume on the afternoon of June 21 (Table 6). Strictly on a dilution basis the propene content of the plume should decrease by about 50% at a distance of 8 miles downwind of the refinery. The observed decrease was nearly 75% (12.5 $\mu g/m^3$ at .5 miles to 3 $\mu g/m^3$ at 8 miles). At 4 miles, however, the percentage decrease in propene is the same as the dilution factor (25%). Thus on this basis it appears that chemical degradation of propene begins at some point beyond 4 miles from the refinery and is clearly evident at 8 miles downwind. Wind speeds during this sampling period averaged about 10 mph, which means the 8 mile sample left the refinery approximately one hour earlier.

The same conclusion can be reached by ratioing propene to the much less reactive hydrocarbon n-pentane. This procedure eliminates dilution as a variable since both species are plume constituents from the beginning. Examination of the propene/n-pentane ratio in the three samples collected on the afternoon of June 21 shows a drop in propene content at the 8 mile collection point:

Distance from Refinery	Propene/n-pentane
.5 miles	.6
4	.6
8	.3

That the lower ratio at 8 miles is truely due to a decrease in propene and not an increase in n-pentane is substantiated by the fact that the ratio of pentane to other low reactivity hydrocarbons is nearly constant at all distances. For example, the corresponding n-butane/n-pentane ratio is 2.6 at each of the three distances. Other flights showed a similar reduction in propene content with distance.

The amount of NO_x we measured in the plume was relatively small. This is not unexpected based on the emission figures presented in Table 3. Maximum NO_x values of about 55 ppb were recorded at the ground trailer. Bag samples collected in the aircraft never exceeded 45 ppb and were usually less that 20 ppb. At distances greater than five miles downwind of the refinery, plume NO_x levels were indistinguishable from background concentrations. As can be seen in Figure 2, by the time the plume reached the trailer monitoring site (1.5 miles from refinery) most of the NO_x was in the form of NO_2. Since the plume is richest in NO_2, it is not surprising that it is deficient in ozone. This also is clearly evident in Figure 2 since in most cases NO_2 and O_3 traces are nearly mirror images of one another. Thus the ozone-nitric oxide reaction appears to be primarily responsible for this rapid conversion of NO to NO_2.

Aircraft traverses of the plume at distances of less than a mile downwind of the refinery always showed depressed ozone content relative to background air. Figure 11 shows a strip chart recording of ozone concentration for three successive passes through the plume at about one mile from the refinery. At greater distances ozone depletions appear sometimes and not at others. For example, in the 2 and 8 mile traverses shown in Figures 4 and 5, a small decrease in ozone can be seen at the 1500' elevation but little effect below that.

Thus as the plume leaves the refinery, it carries along a large burden of mostly unreactive hydrocarbons and relatively small amounts NO_x mainly in the form of NO_2. Also in the initial stages it is somewhat depleted in ozone content.

Photochemical oxidant production from various sources is of special concern at the present time. Consequently we were interested in checking for ozone build-up in the plume as it proceeded downwind. Ozone survey flights were conducted on the afternoons of June 13, 15, 20, 23 and 24. The general flight pattern covered an area fr m about 15 miles upwind of the refinery to 40 miles downwind. Before each flight a careful examination of the morning wind speed and direction provided the approximate downwind position of the

TABLE 9. HYDR[illegible]BON RATIOS WITHIN THE PLUME

	2-Mile Downwind Ground Samples (6/16)		2-Mile Downwind Aircraft Samples (6/21)		Ground Fenceline Samples	
	Tank Side of Plume	Non-Tank Side of Plume	Tank Side of Plume	Non-Tank Side of Plume	Tanks 6/19	Tanks 6/22
Propane	25.0	129	37.5	99.5	1539	27.5
i-Butane	15.5	74.5	18.0	58.0	495	12.5
n-Butane	36.0	147	35.0	75.5	1416	24.5
Total $\mu g/m^3$	76.5	351	90.5	233.0	3450	64.5
i-Pentane	16.0	11.0	22.5	17.5	531	10.5
n-Pentane	8.0	5.5	16.5	10.5	506	6.5
i-Hexane	4.0	2.5	5.5	5.5	129	3.0
n-Hexane	4.0	4.0	9.5	5.5	152	5.5
Total $\mu g/m^3$	32.0	23.0	54.0	39.0	1318	25.5
Ratio $\frac{C_3-C_4}{C_5-C_6}$	2.4	15.3	1.6	6.0	2.6	2.5

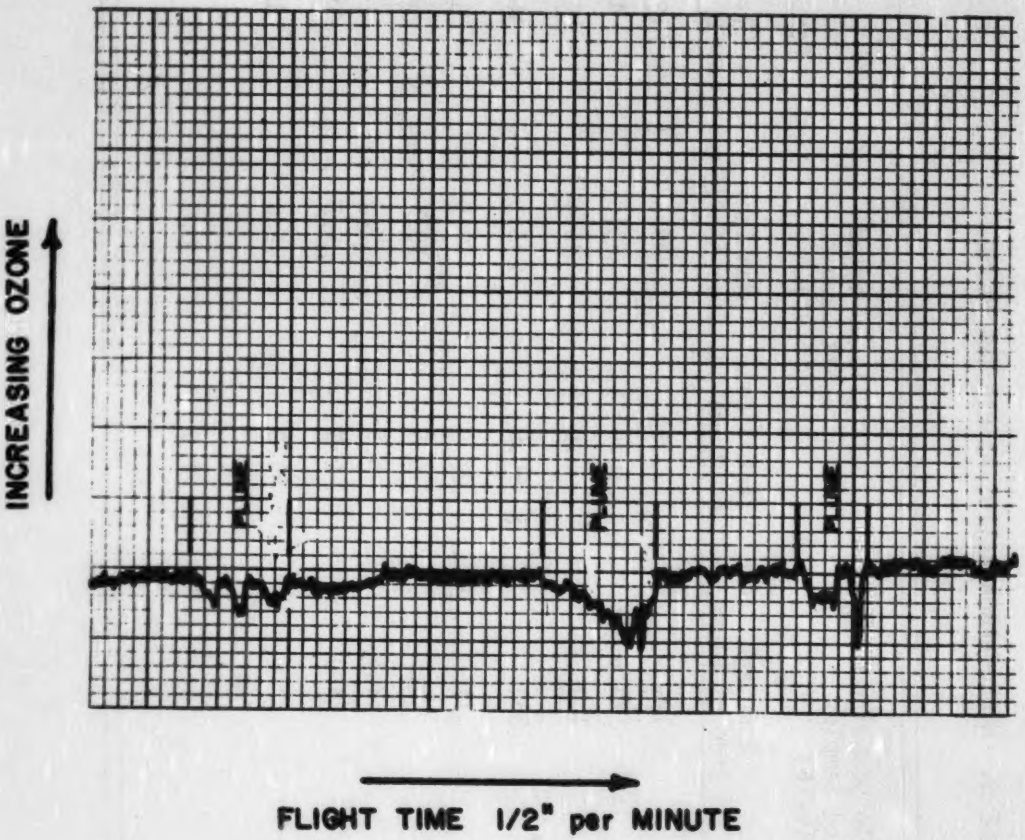


Figure 11. Ozone recording taken during aircraft passes through the plume.

plume. On each of the flights we feel sampling occurred in the area where plume associated ozone could have developed. However, no significant increase in ozone levels was observed. Figures 12 and 13 show survey flight paths for two different days. Arrows represent wind trajectories and thus mark the path a parcel of air traveled as it left the refinery. Each arrow represents the distance the parcel traveled in one hour beginning, in both cases, at the refinery at 12 noon. Wind trajectory vectors are included for two reasons. First to show that sampling actually took place in the area of plume drift and second to indicate the speed of air movement prior to and during the sampling period. This latter feature is quite important since it dictates the time span over which photochemical oxidant could be formed. As can be seen in the two survey maps, this time span is quite short - 3.5 hours on June 20 and 3 hours on June 23. Considering this relatively short exposure to sunlight and the unreactive nature of most plume hydrocarbons, it is not surprising that we didn't observe any plume associated oxidant build-up.

One notable feature in Figure 12 and 13 is the dependence of the absolute magnitude of ozone levels on wind direction. Ozone concentrations in the 60 ppb range accompanied winds from the southwest quadrant (June 20), while the ozone levels were lower by a factor of two when northerly winds prevailed. This is certainly not a refinery plume associated phenomena but rather appears to be related to synoptic scale weather systems.

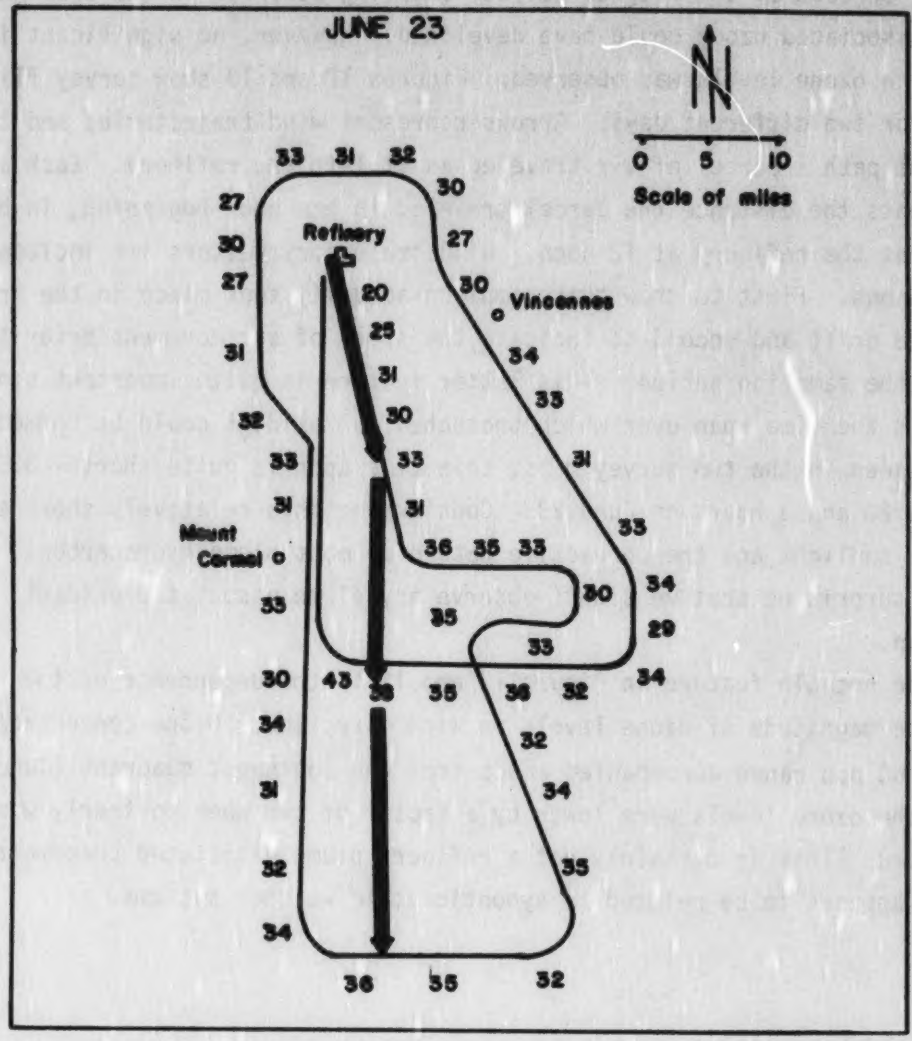

JUNE 23
N
0 5 10
Scale of miles
Refinery
Vincennes
Mount Carmel
33 31 32
30
27
30
27
27
30
20
25
31
34
31
33
32
30
33
33
31
31
33
36 35 33
35
34
30
35
29
33
30 43 38 35 36 32
34
34
32
31
34
32
35
34
36 35 32

Figure 12. Aircraft flight path on the afternoon of June 23, 1974 with ozone concentrations (ppb) marked at specific points along the route.

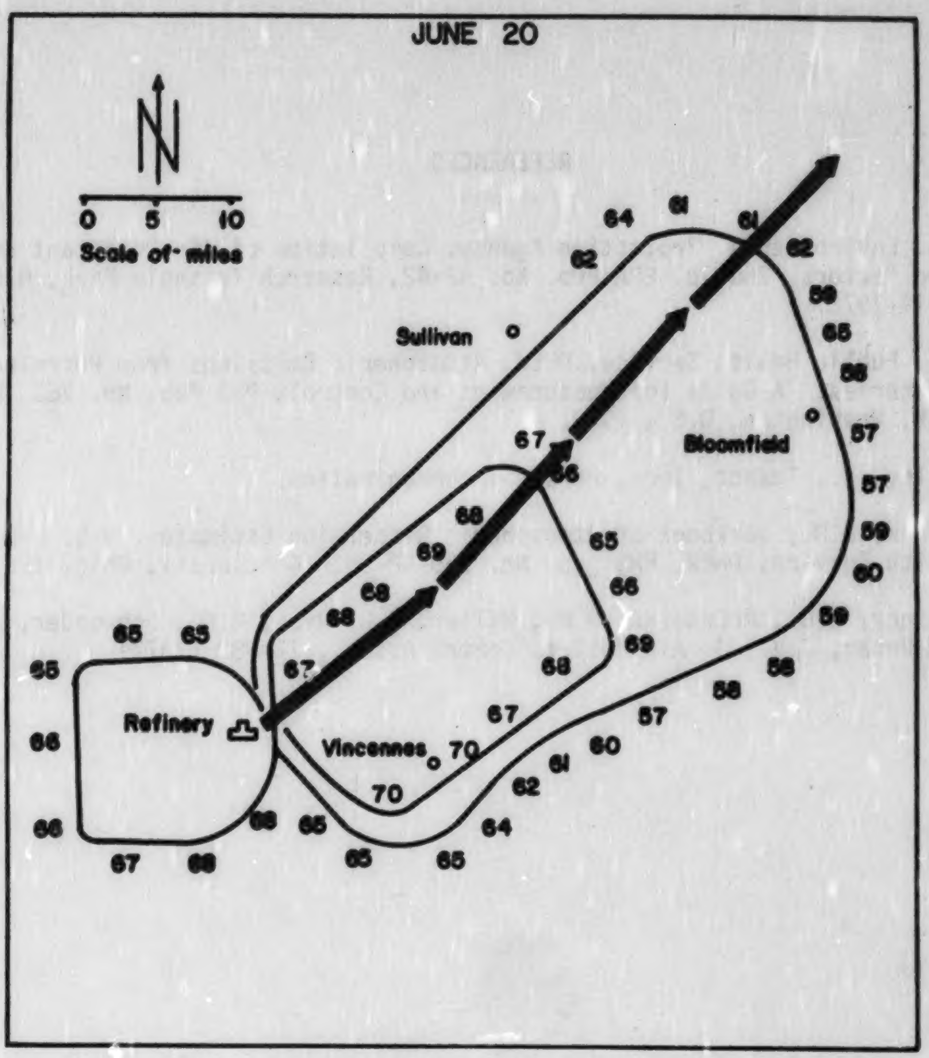

JUNE 20
N
0 5 10
Scale of miles
Sullivan
Bloomfield
Refinery
Vincennes
64
61
61
62
62
59
65
58
57
57
59
60
59
58
58
57
60
61
62
64
65
65
65
66
66
66
67
67
68
69
68
69
68
68
67
66
65
65
65
65
66
66
67
68
70
70
67

Figure 13. Aircraft flight path on the afternoon of June 20, 1974 with ozone concentrations (ppb) marked at specific points along the route.

REFERENCES

1. U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, 2nd Ed. EPA Pub. No. AP-42, Research Triangle Park, N.C., April 1973.

2. U.S. Public Health Service, DHEW, Atmospheric Emissions from Petroleum Refineries: A Guide for Measurement and Control, PHS Pub. No. 763, USPHS DHEW, Washington, D.C., 1960.

3. Bailey, B., Texaco, Inc., Personal communication.

4. Turner, D.B., Workbook of Atmospheric Dispersion Estimates, U.S. Public Health Service, DHEW, PHS pub. No. 999-AP-26. Cincinnati, Ohio, 1969.

5. Edinger, J.G., McCutchan, M.H., Miller, P.R. Ryan, B.C., Schroeder, M.J., and Behar, J.V., J. Air Pollut. Contr. Assoc., 22 882 (1972).

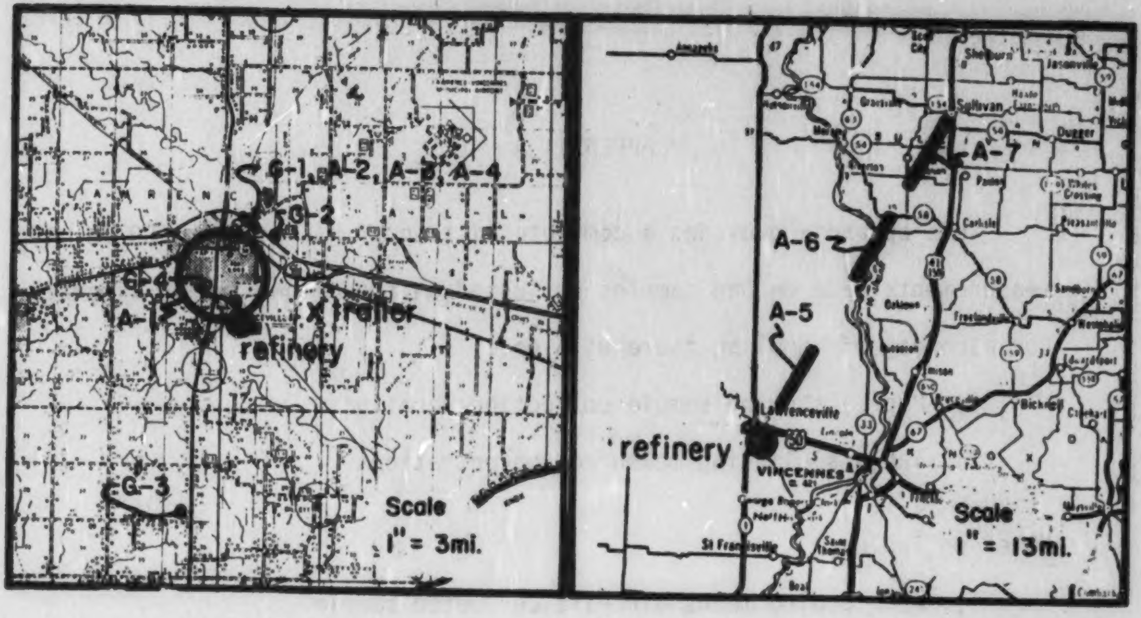
APPENDIX A

This appendix provides a complete listing of hydrocarbon, CO and NO_x measurements made on bag samples collected on the ground and by aircraft. For each day of sampling there will be:

1) Map(s) showing sample collection locations
2) Table(s) listing measured concentrations

Notes on Tables:

1) A in coding means aircraft collected sample.
2) G in coding means ground collected sample.
3) * means hydrocarbon concentration was less than .5 $\mu g/m^3$.


G-1, A-2, A-3, A-4
G-2
G-4
A-1
X trailer
refinery
G-3
Scale
1" = 3mi.
A-7
A-6
A-5
Sullivan
Lawrenceville
refinery
VINCENNES
Scale
1" = 13mi.

BAG	Location
G-1	Morn, Highway 50 - 1 mile east Highway #1
G-2	Morn, Highway 50 - 1.6 mile east Highway #1
G-3	Morn, 3 mile south of refinery
G-4	Aft, refinery - north boundary
A-1	Morn, city survey, 1000'
A-2	Morn, 2 mile integrated, 500'
A-3	Morn, 2 mile, 500'
A-4	Morn, 2 mile, 1000'
A-5	Aft, 2-4 mile downwind, 1000'
A-6	Aft, 16-20 mile downwind, 1000'
A-7	Aft, 26-30 mile downwind, 1000'

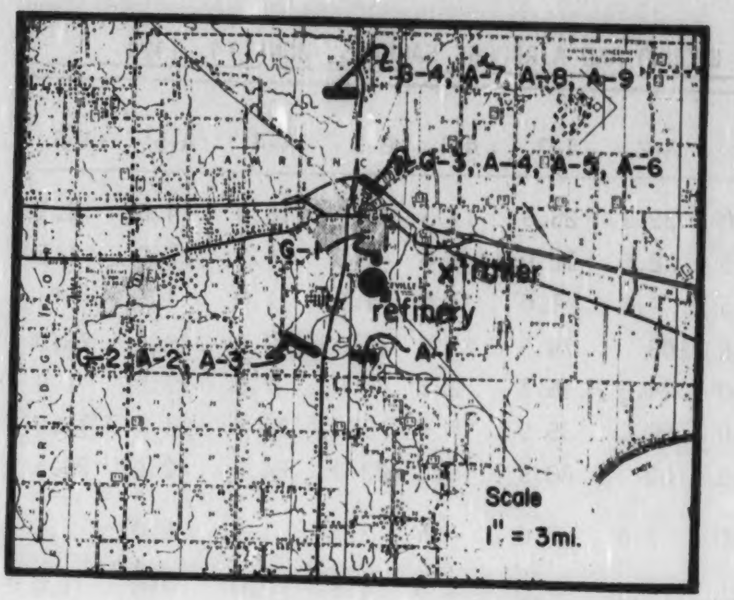
Figure A-1. Location of Hydrocarbon Samples Collected on June 13, 1974.

TABLE A-1. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 13, 1974

	G-1	G-2	G-3	G-4	A-1	A-2	A-3	A-4
Ethane	14.5	17.5	305	51.5	6.0	12.5	11.0	16.5
Ethylene	6.5	12.0	10.0	30.0	11.5	9.0	7.5	10.5
Acetylene	1.5	2.5	4.5	.5	1.0	1.0	.5	1.0
Propane	30.5	35.5	848	205	9.0	30.0	22.0	43.5
Propene	4.0	5.5	10.5	41.5	1.5	4.5	3.0	5.0
i-Butane	14.5	9.0	145	65.0	3.0	11.5	10.5	23.5
n-Butane	39.5	31.0	481	118	7.0	28.0	32.0	57.5
neo-Pentane 1-Butene	3.0	2.0	3.5	2.5	.5	2.0	1.0	2.5
i-Butene	2.0	2.5	5.5	4.0	.5	2.5	1.0	3.5
t-2-Butene Propyne	1.5	.5	6.5	1.0	*	2.0	.5	2.0
c-2-Butene	1.0	*	7.0	1.5	*	1.0	*	2.0
i-Pentane	22.5	20.0	115	34.5	8.5	14.5	25.0	27.5
n-Pentane	15.0	17.5	129	10.0	3.5	11.0	12.0	19.5
Cyclopentane	1.0	2.0	16.5	1.0	*	1.5	1.5	4.0
1-Pentene	.5	1.5	2.0	1.0		1.0	1.0	2.5
i-Hexane	8.0	8.0	28.0	5.0	1.5	5.5	4.5	9.0
3-Methylpentane	2.5	4.0	16.5	5.0	2.0	5.0	2.0	5.5
n-Hexane	5.5	8.5	33.0	6.0	2.0	6.5	5.5	9.5
Cyclohexane	1.5	5.5	10.5	*	*	3.5	*	3.5
Total $\mu g/m^3$	175	185	2177	583	57.5	153	141	249
NMTHC (ppm)	.4	.5	3.6	.3	.2	.4		.6
CO (ppm)	1.3	1.3	.7	10.2	1.1	1.4		1.8
CH_4 (ppm)	1.6	1.7	1.9	1.7	1.6	1.6		1.7
NO_x (ppb)	27	28	18	17	14	14		

TABLE A-1. (cont.)

	A-5	A-6	A-7
Ethane	12.5	6.5	5.0
Ethylene	18.5	17.5	14.5
Acetylene	1.0	.5	.5
Propane	38.0	9.0	7.5
Propene	11.0	8.5	9.5
i-Butane	14.5	2.5	2.0
n-Butane	29.0	5.0	5.0
neo-Pentane 1-Butene	4.0	2.0	1.5
i-Butene	6.0	4.0	4.5
t-2-Butene Propyne	2.0	.5	1.5
c-2-Butene	2.0	.5	1.0
i-Pentane	10.5	4.5	2.5
n-Pentane	5.5	2.0	2.0
Cyclopentane	1.0	*	*
1-Pentene	*	2.0	*
i-Hexane	2.5	*	3.0
3-Methylpentane	1.0	1.0	*
n-Hexane	2.5	1.5	1.0
Cyclohexane	.5	*	.5
Total $\mu g/m^3$	162	67.5	61.5
NMTHC (ppm)	.5	.2	.2
CO (ppm)	6.2	4.0	3.8
CH_4 (ppm)	1.6	1.6	1.6
NO_x (ppb)	15	14	13


G-4, A-7, A-8, A-9
G-3, A-4, A-5, A-6
G-1
X tower
refinery
G-2, A-2, A-3
A-1
Scale
1" = 3mi.

BAG	LOCATION
G-1	Morn, refinery - north boundary
G-2	Morn, 2 mile downwind (under plane)
G-3	Aft, 2 mile downwind (under plane)
G-4	Aft, 4 mile downwind (under plane)
A-1	Morn, 2 mile downwind, 500'
A-2	Morn, 2 mile downwind, 500'
A-3	Morn, 2 mile downwind, 1000'
A-4	Aft, 2 mile downwind, 500'
A-5	Aft, 2 mile downwind, 1000'
A-6	Aft, 2 mile downwind, 1500'
A-7	Aft, 4 mile downwind, 500'
A-8	Aft, 4 mile downwind, 1000'
A-9	Aft, 4 mile downwind, 1500'

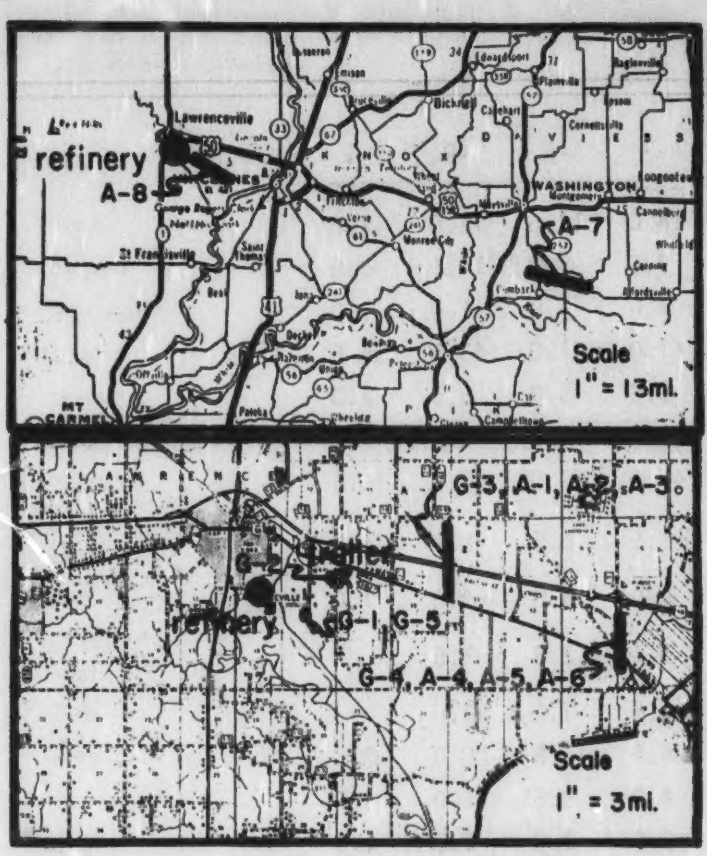
Figure A-2. Location of Hydrocarbon Samples Collected on June 14, 1974.

TABLE A-2. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 14, 1974

	G-2	A-2	A-3	A-1	G-3	A-4	A-5	A-6
Ethane	30.0	33.5	25.5	11.5	8.5	16.0	14.0	12.5
Ethylene	10.5	8.5	12.0	7.0	7.5	4.5	20.0	5.5
Acetylene	4.5	1.0	1.0	1.0	1.5	1.0	1.5	*
Propane	63.5	105	75.5	22.5	16.0	48.5	45.5	26.0
Propene	4.0	14.5	16.5	2.5	5.0	7.5	17.0	5.0
i-Butane	22.0	50.0	35.5	9.0	8.0	26.0	21.0	16.0
n-Butane	63.5	100	68.5	19.5	22.0	54.0	42.0	29.5
neo-Pentane 1-Butene	2.0	3.0	6.0	.5	3.5	1.5	5.0	.5
i-Butene	3.5	3.5	7.0	1.0	4.5	2.0	7.0	1.0
t-2-Butene Propyne	2.5	2.0	4.0	.5	2.0	.5	3.0	*
c-2-Butene	1.5	1.5	3.0	*	1.5	1.0	2.0	.5
i-Pentane	34.0	48.0	35.5	12.5	18.5	23.0	18.0	15.5
n-Pentane	24.0	23.0	18.0	6.5	13.0	12.0	10.5	6.0
Cyclopentane	2.0	2.5	3.0	.5	1.0	1.5	1.5	*
1-Pentene	.5	2.0	2.5	*	1.0	1.0	2.5	2.0
i-Hexane	10.0	7.0	6.0	2.5	6.5	4.5	4.5	2.0
3-Methylpentane	6.0	5.5	3.0	2.5	3.0	3.5	2.5	1.0
n-Hexane	11.0	9.0	7.0	3.5	5.5	8.5	5.0	2.5
Cyclohexane	4.5		2.5		1.0		1.5	*
Total $\mu g/m^3$	300	420	332	103	130	217	222	126
NMTHC (ppm)	1.1	1.1	.8		.3	.6	.8	
CO (ppm)	1.9	1.7	4.7		4.2	1.1	11.3	
CH_4 (ppm)	1.8	1.7	1.7		1.7	1.7	1.7	
NO_x (ppb)	22		26		24		21	

TABLE A-2. (cont.)

	G-4	A-7	A-8	A-9	G-1
Ethane	15.5	14.0	11.5	15.0	11.0
Ethylene	6.5	7.5	5.0	14.0	5.5
Acetylene	1.0	1.0	1.0	1.0	1.0
Propane	47.0	41.0	31.0	43.5	16.5
Propene	6.0	5.0	5.0	5.5	2.0
i-Butane	25.5	21.5	16.5	24.5	7.5
n-Butane	53.0	46.0	37.0	51.0	15.5
neo-Pentane 1-Butene	4.0	1.5	3.5	2.0	.5
i-Butene	5.0	4.0	4.0	3.0	1.0
t-2-Butene Propyne	2.5	.5	2.5	1.5	.5
c-2-Butene	1.5	.5	1.5	1.0	*
i-Pentane	18.0	16.5	16.5	20.0	8.5
n-Pentane	11.5	9.0	9.5	11.0	5.5
Cyclopentane	2.5	2.0	1.0	1.0	1.0
1-Pentene	2.0	1.0	.5	1.0	.5
i-Hexane	5.5	3.0	5.0	5.0	2.5
3-Methylpentane	3.0	2.0	3.5	2.5	2.5
n-Hexane	4.0	4.5			3.5
Cyclohexane	3.5	*	2.0	1.5	1.0
Total $\mu g/m^3$	218	181	157	204	86.0
NMTHC (ppm)	.5	.5	.5	.8	.3
CO (ppm)	1.7	1.6	2.0	2.0	.8
CH_4 (ppm)	1.6	1.7	1.6	1.6	1.8
NO_x (ppb)	23				20


Lawrenceville
refinery
A-8
WASHINGTON
A-7
Scale
1" = 13mi.
MT CARMEL
G-3, A-1, A-2, A-3
G-2
trailer
refinery
G-1, G-5
G-4, A-4, A-5, A-6
Scale
1" = 3mi.

BAG	LOCATION
G-1	Morn, 1 mile east of refinery
G-2	Morn, trailer manifold sample
G-3	Morn, 4 mile downwind, (under plane)
G-4	Morn, 8 mile downwind, (under plane)
G-5	Aft, 1 mile east of refinery
A-1	Morn, 4 mile downwind, 500'
A-2	Morn, 4 mile downwind, 1000'
A-3	Morn, 4 mile downwind, 1500'
A-4	Morn, 8 mile downwind, 500
A-5	Morn, 8 mile downwind, 1000'
A-6	Morn, 8 mile downwind, 1500'
A-7	Aft, 34 mile downwind, 1000'
A-8	Aft, 2 mile downwind, 1000'

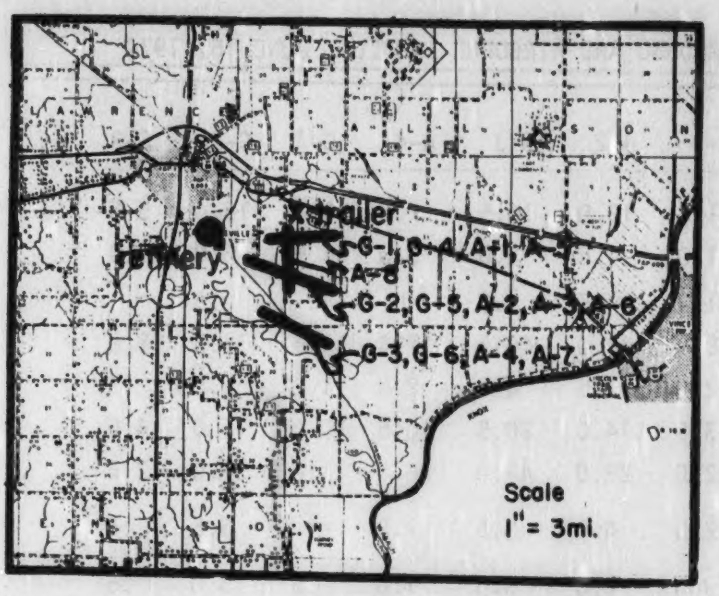
Figure A-3. Location of Hydrocarbon Samples Collected on June 15, 1974.

TABLE A-3. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 15, 1974

	G-3	A-1	A-2	A-3	G-4	A-4	A-5	A-6
Ethane	5.5	16.0	19.0	9.5	3.0	12.5	9.5	6.5
Ethylene	6.5	5.5	10.5	12.0	6.0	20.0	5.0	6.0
Acetylene	*	*	.5	.5	.5	.5	.5	*
Propane	27.0	40.0	67.5	26.5	16.0	30.5	17.5	21.0
Propene	5.0	5.0	7.0	7.0	2.0	4.0	3.0	6.5
i-Butane	12.5	20.0	29.0	7.5	7.0	15.0	9.0	8.0
n-Butane	30.5	44.0	63.0	15.5	17.0	33.5	23.0	18.5
neo-Pentane 1-Butene	1.0	1.5	5.0	2.0	.5	3.0	2.0	1.0
i-Butene	1.5	1.5	4.5	2.5		3.5	2.0	1.5
t-2-Butene Propyne	1.0	.5	3.0	1.5	*	2.0	*	*
c-2-Butene	.5	.5	2.5	.5	*	2.5	*	*
i-Pentane	18.5	23.0	26.5	8.0	9.5	17.5	11.0	11.0
n-Pentane	10.5	13.0	14.5	5.0	4.5	8.5	6.5	5.0
Cyclopentane	1.0	2.0	2.5	.5	1.0	.5	.5	.5
1-Pentene	.5	1.0	2.0	*	.5	.5		.5
i-Hexane	4.0	4.5	10.0	2.0	1.5	4.0	3.5	2.5
3-Methylpentane	3.5	4.0	6.0	1.0	1.5	2.5	2.0	1.0
n-Hexane	5.0	5.5	7.5	1.5	1.5	6.0	4.5	1.5
Cyclohexane			3.0			1.0		
Total $\mu g/m^3$	135	189	289	105	72.5	170	102	92.0
NMTHC (ppm)	.4	.6	.7	.4	.3	.7	.4	.3
CO (ppm)	1.4	1.6	1.8	1.2	1.4	1.3	1.0	1.5
CH_4 (ppm)	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6
NO_x (ppb)	21			14	18			18

TABLE A-3. (cont.)

	A-7	A-8	G-1	G-2	G-5
Ethane	5.0	5.0	48.5	41.0	6.0
Ethylene	5		11.5	4.1	1.5
Acetylene			.5	*	.5
Propane	5.5	9.0	153	173	152
Propene			25.0	12.5	9.0
i-Butane	3.5	5.0	84.0	96.0	93.0
n-Butane	7.0	10.5	222	184	180
neo-Pentane 1-Butene	.5	1.5	10.5	2.5	4.0
i-Butene	1.5	1.0	9.5	3.5	4.5
t-2-Butene Propyne	*	.5	7.5	2.0	2.5
c-2-Butene		*	6.0	2.0	1.5
i-Pentane	3.5	7.5	189	29.0	24.0
n-Pentane	1.5	3.5	110	14.5	12.0
Cyclopentane	.5	.5	7.0	1.0	1.0
1-Pentene	*	*	5.0	1.5	1.5
i-Hexane	1.0	1.0	41.0	5.5	6.0
3-Methylpentane	*	.5	23.0	4.5	5.0
n-Hexane	*	*	37.5	6.5	6.5
Cyclohexane	*	*	7.0	2.5	*
Total $\mu g/m^3$	33.5	51.0	1008	588	512
NMTHC (ppm)	.1	.2	2.1	.9	1.4
CO (ppm)	.8	1.2	1.6	1.2	1.7
CH_4 (ppm)	1.6	1.6	1.6	1.6	1.6
NO_x (ppb)	10	10	38	42	19


trailer
refinery
G-1, G-4, A-1, A-5
A-8
G-2, G-5, A-2, A-3, A-6
G-3, G-6, A-4, A-7
Scale
1" = 3mi.

BAG	LOCATION
G-1	Morn, flare-side bag (under plane)
G-2	Morn, middle bag (under plane)
G-3	Morn, tank-side bag (under plane)
G-4	Aft, flare-side bag (under plane)
G-5	Aft, middle bag (under plane)
G-6	Aft, tank-side bag (under plane)
A-1	Flare-side, 1-2 mile, 500'
A-2	Middle, 0-1 mile, 500'
A-3	Middle, 1-2 mile, 500'
A-4	Tank-side, 0-2 mile, 500'
A-5	Flare-side, 1-2 mile, 500'
A-6	Middle, 1-2 mile, 500'
A-7	Tank-side, 1-2 mile, 500'
A-8	Integrated across, 2 mile, 500'

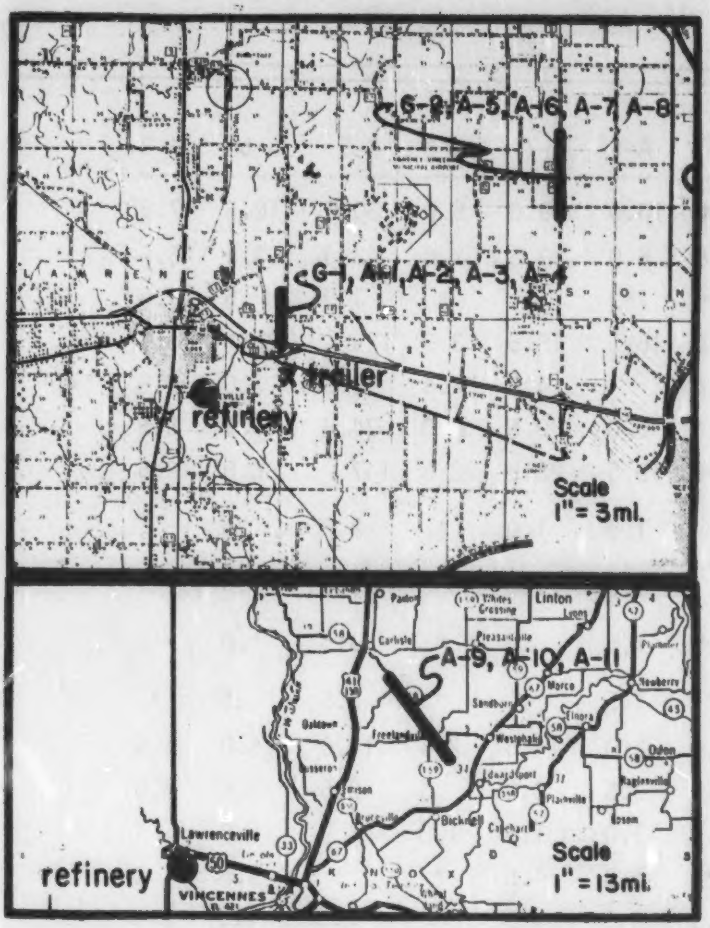
Figure A-4. Location of Hydrocarbon Samples Collected on June 16, 1974.

TABLE A-4. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 16, 1974

	A-1	A-2	A-3	A-4	G-1	G-2	G-3
Ethane	11.5	19.0	16.5	7.5	10.0	16.0	5.5
Ethylene	1.0	4.0	2.0	5.0	5.5	6.0	2.0
Acetylene	1.0	.5	.5	*	*	.5	
Propane	28.5	41.0	40.5	17.0	16.5	34.5	8.0
Propene	2.0	11.5	4.5	2.5	1.5	4.0	.5
i-Butane	13.5	14.0	20.5	10.5	10.0	15.0	4.5
n-Butane	32.0	29.0	41.0	26.5	21.0	37.0	12.5
neo-Pentane 1-Butene	2.5	4.0	3.5	1.0	*	3.5	.5
i-Butene	3.0	3.0	3.5	1.0	.5	3.0	.5
t-2-Butene Propyne	3.0	3.0	3.0	.5	*	3.0	*
c-2-Butene	1.5	3.0	1.5	.5	.5	1.5	*
i-Pentane	17.0	21.0	21.5	26.5	11.5	22.0	11.0
n-Pentane	6.0	11.0	8.5	12.0	3.5	12.5	6.5
Cyclopentane	.5	2.0	.5	1.5	.5	1.0	1.0
1-Pentene	*	3.0	1.0	.5	*	1.0	*
i-Hexane	2.0	6.0	3.0	5.0	1.0	4.0	4.0
3-Methylpentane	1.0	3.0	1.5	3.5	1.0	2.0	3.5
n-Hexane	2.5	6.5	4.0	5.0	1.5	8.5	2.5
Cyclohexane	1.0	2.0	.5	1.0	*	2.0	*
Total μg/m^3	130	187	178	127	84.5	177	62.5
NMTHC (ppm)	.4	.5	.6	.5	.2	.4	.2
CO (ppm)	1.0	2.6	1.3	1.0	.9	1.1	.8
CH_4 (ppm)	1.6	1.6	1.6	1.6	1.6	1.6	1.7
NO_x (ppb)				12	15	15	12

TABLE A-4. (cont.)

	A-5	A-6	A-7	G-4	G-5	G-6	A-8
Ethane	6.0	10.0	9.0	5.0	30.5	10.5	7.5
Ethylene	5.5	6.0	3.5	3.0	3.0	3.5	5.5
Acetylene	.5	*	*	*	1.0	.5	.5
Propane	5.0	16.5	18.5	3.5	129	25.0	16.0
Propene	2.0		4.0	2.5	3.5	2.0	2.5
i-Butane	2.0	8.0	9.5	3.0	74.5	15.5	9.5
n-Butane	7.0	19.5	22.5	2.5	147	36.0	19.5
neo-Pentane 1-Butene		1.0	1.0	*	2.5	1.0	
i-Butene		1.5	1.0	*	3.5	1.5	
t-2-Butene Propyne	1.5	1.5	.5	*	3.5	1.0	
c-2-Butene	*	1.5	*	*	2.5	.5	*
i-Pentane	7.0	12.0	14.5	2.5	11.0	16.0	5.5
n-Pentane	3.5	7.5	8.0	.5	5.5	8.0	3.0
Cyclopentane	1.0	1.0	1.5	1.0	2.0	1.0	
1-Pentene	*	1.0	1.5	*	*	1.5	1.0
i-Hexane	1.5	3.5	4.0	*	2.5	4.0	2.0
3-Methylpentane	.5	1.5	3.0	1.0	1.5	3.0	.5
n-Hexane	1.5	6.0	5.0	1.0	4.0	4.0	.5
Cyclohexane		*	*	*	1.5	*	*
Total $\mu g/m^3$	44.5	98.0	107	25.5	429	135	73.5
NMTHC (ppm)	.3	.5	.5	.1	.8	.4	.3
CO (ppm)	1.2	1.4	1.4	.9	.8	1.0	.8
CH_4 (ppm)	1.6	1.6	1.6	1.6	1.6	1.6	1.6
NO_x (ppb)				9	11	9	8


G-2, A-5, A-6, A-7, A-8
G-1, A-1, A-2, A-3, A-4
trailer
refinery
Scale
1" = 3mi.
Linton
Whites Crossing
Carlisle
Pleasantville
A-9, A-10, A-11
Sandborn
Newberry
Elnora
Westphalia
Odon
Freelandville
Oaktown
Edwardsport
Plainville
Bicknell
Lawrenceville
refinery
VINCENNES
Scale
1" = 13mi.

BAG	LOCATION
G-1	Morn, 2 mile downwind
G-2	Morn, 8 mile downwind
A-1	Morn, 2 mile downwind, 500'
A-2	Morn, 2 mile downwind, 750'
A-3	Morn, 2 mile downwind, 1000'
A-4	Morn, 2 mile downwind, 1500'
A-5	Morn, 8 mile downwind, 500'
A-6	Morn, 8 mile downwind, 750'
A-7	Morn, 8 mile downwind, 1000'
A-8	Morn, 8 mile downwind, 1500'
A-9	Aft, 22 mile downwind, 1000'
A-10	Aft, 22 mile downwind, 1500'
A-11	Aft, 22 mile downwind, 2000'

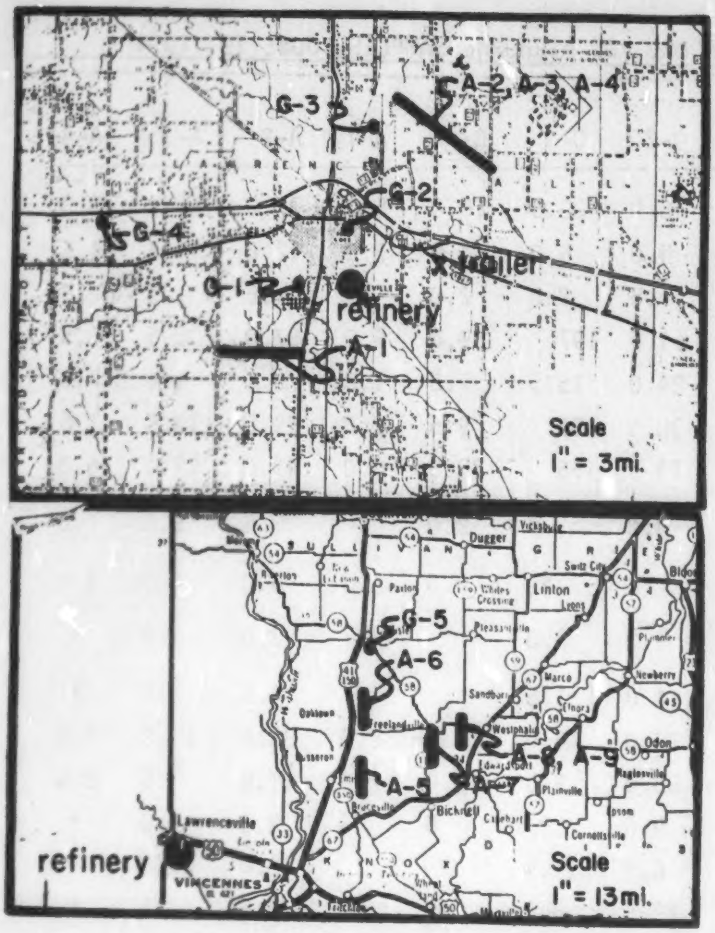
Figure A-5. Location of Hydrocarbon Samples Collected on June 17, 1974.

TABLE A-5. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 17, 1974

	G-1	A-1	A-2	A-3	A-4	G-2	A-5	A-6
Ethane	26.5	30.0	15.0	39.0	24.0	12.5	7.0	14.0
Ethylene	8.0	6.0	3.0	10.0	4.0	3.5	3.5	4.0
Acetylene	.5	.5	.5	1.0	*	.5	.5	1.0
Propane	60.5	81.0	54.0	113	106	40.5	9.5	32.0
Propene	14.5	12.5	8.5	16.5	12.5	3.0	1.0	4.0
i-Butane	29.5	42.5	30.0	66.0	70.5	15.0	8.0	15.5
n-Butane	78.0	97.0	73.5	123	139	33.5	12.0	34.0
neo-Pentane 1-Butene	2.0	6.0	2.0	4.5	3.5		.5	5.0
i-Butene	2.0	4.5	2.0	4.5	3.5	.5	.5	3.0
t-2-Butene Propyne	2.0	5.0	2.0	4.0	2.0	*	*	3.0
c-2-Butene	2.0	3.5	2.0	2.5	1.5	*	*	2.0
i-Pentane	54.5	48.5	43.0	45.5	33.0	10.0	6.0	12.0
n-Pentane	31.5	26.5	24.5	30.0	22.0	7.0	3.0	8.0
Cyclopentane	6.5	4.0	2.5	2.5	3.0	1.0	*	.5
1-Pentene	2.5	3.5	1.5	5.5	2.0	*	*	.5
i-Hexane	11.5	11.0	8.5	12.0	8.0	2.5	1.5	3.5
3-Methylpentane	7.0	6.0	5.0	7.5	6.5	1.5	.5	2.5
n-Hexane	12.5	9.5	9.0	13.5	10.5	3.0	1.5	3.5
Cyclohexane	5.0	3.0	3.0	5.5		*	*	1.0
Total $\mu g/m^3$	357	401	290	514	452	134	55.0	149
NMTHC (ppm)	.9	1.0	.8	1.4	1.7	.5	.4	.4
CO (ppm)	1.3	1.4	1.4	2.9	2.1	1.2	1.2	.9
CH_4 (ppm)	1.7	1.7	1.6	1.7	1.6	1.6	1.6	1.6
NO_x (ppb)	21					14		

TABLE A-5. (cont.)

	A-7	A-8	A-9	A-10	A-11
Ethane	14.5	12.0	9.0	9.0	5.5
Ethylene	4.0	3.5	8.5	11.5	5.5
Acetylene	.5	.5	*	.5	*
Propane	33.5	26.0	7.5	13.5	11.5
Propene	5.0	3.5	5.0	8.0	4.5
i-Butane	16.5	14.0	3.5	8.0	4.5
n-Butane	38.0	30.5	11.0	19.0	14.5
neo-Pentane 1-Butene	2.5	4.5	*		*
i-Butene	1.5	3.5	.5		.5
t-2-Butene Propyne	1.5	3.5	*		*
c-2-Butene	1.0	2.5	*	*	*
i-Pentane	12.0	13.5	8.0	14.0	11.5
n-Pentane	8.0	7.5	3.0	5.0	4.0
Cyclopentane	1.0	2.0	.5	.5	1.5
1-Pentene	*	1.5	*	*	.5
i-Hexane	4.0	3.0	1.5	2.5	2.0
3-Methylpentane	2.5	1.5	1.0	1.0	2.0
n-Hexane	4.5	3.0	.5	2.0	1.5
Cyclohexane	1.5	1.0	*	*	*
Total $\mu g/m^3$	152	137	60.0	93.5	69.5
NMTHC (ppm)	.5	.5	.3	.3	.3
CO (ppm)	1.2	1.2	1.4	3.4	2.4
CH_4 (ppm)	1.6	1.6	1.6	1.7	1.6
NO_x (ppb)					


G-3
A-2, A-3, A-4
G-2
G-4
x tower
G-1
refinery
A-1
Scale
1" = 3mi.
G-5
A-6
A-8
A-9
A-5
A-7
Dugger
Linton
Lawrenceville
refinery
VINCENNES
Scale
1" = 13mi.

BAG	LOCATION
G-1	Morn, tank farm sample
G-2	Morn, downtown, 6th & Jefferson
G-3	Morn, 2.5 mile downwind
G-4	Morn, clean air bag, 4½ mile ENE of refinery
G-5	Aft, 18 mile downwind, (3 mile W Lawrenceville)
A-1	Morn, upwind, 1000'
A-2	Morn, 4 mile downwind, 500'
A-3	Morn, 4 mile downwind, 1000'
A-4	Morn, 4 mile downwind, 2000'
A-5	Aft, 16 mile downwind, 1000'
A-6	Aft, 19 mile downwind, 1000'
A-7	Aft, 22 mile downwind, 1000'
A-8	Aft, 24 mile downwind, 1000'
A-9	Aft, 25 mile downwind, 1500'

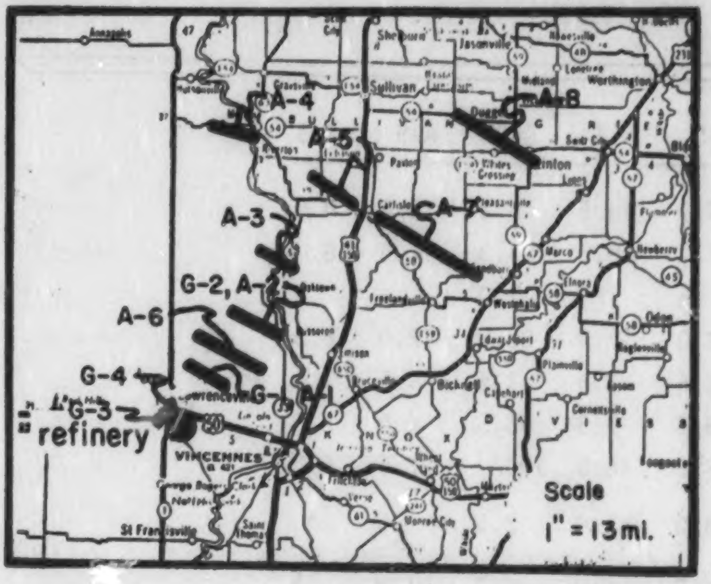
Figure A-6. Location of Hydrocarbon Samples Collected on June 19, 1974.

TABLE A-6. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 19, 1974

	G-1	G-2	G-3	G-4	A-1	A-2	A-3	A-4
Ethane	576	28.0	30.5	19.0	5.0	17.0	12.5	6.0
Ethylene	5.5	9.0	5.0	4.0	3.0	12.0	11.5	14.5
Acetylene	*	.5	2.0	2.0	*	.5	.5	.5
Propane	1539	61.5	197	39.0	5.0	57.0	32.5	6.5
Propene	1.0	24.0	15.5	1.5	1.0	10.5	9.0	7.5
i-Butane	495	30.0	129	9.5	2.0	29.5	15.5	1.5
n-Butane	1416	119	156	28.0	6.0	49.0	27.0	6.0
neo-Pentane 1-Butene	9.0	8.0	2.0	2.0	*	5.5	5.0	.5
i-Butene			*	2.5	.5	6.0	4.5	1.5
t-2-Butene Propyne	17.0	7.0	3.0		*	3.0	3.0	*
c-2-Butene	14.5	4.0	1.5		*	4.5	2.5	*
i-Pentane	531	90.0	14.5	9.0	8.0	33.5	13.0	2.5
n-Pentane	506	86.0	9.0	8.0	2.0	19.0	9.5	2.0
Cyclopentane	34.0	9.0	*	.5	*	3.0	1.0	*
1-Pentene	7.5	6.5	.5	*	*	2.5	1.0	*
i-Hexane	129	22.5	5.0	2.5	1.0	7.5	3.5	*
3-Methylpentane	70.5	13.5	3.5	1.0	.5	4.0	1.5	*
n-Hexane	152	32.5	7.5	3.0	.5	7.0	3.5	.5
Cyclohexane	37.5		*	1.0	*	2.0	1.0	*
Total $\mu g/m^3$	5541	552	582	123	34.5	273	158	49.5
NMTHC (ppm)	9.7	1.3	1.2	.3	.2	1.0	.9	.6
CO (ppm)	.7	1.0	2.1	.8	1.0	2.2	1.6	3.5
CH_4 (ppm)	1.9	1.7	1.6	1.6	1.6	1.6	1.6	1.4
NO_x (ppb)	21	105	26	20	16	21	20	18

TABLE A-6. (cont.)

	A-5	A-6	A-7	A-8	A-9	G-5
Ethane	6.0	10.0	10.5	6.5	9.0	8.0
Ethylene	5.5		18.5	7.0	11.5	8.0
Acetylene	*	.5	*	1.0	.5	.5
Propane	7.5	21.0	17.5	28.0	12.0	6.5
Propene	1.5	2.5	2.5	2.5	1.5	1.0
i-Butane	5.5	15.5	8.5	45.5	6.5	2.0
n-Butane	16.0	47.0	16.5	190	22.5	5.5
neo-Pentane 1-Butene	*	4.0	1.0	2.5	.5	*
i-Butene	.5	3.5	2.0	2.5	1.0	.5
t-2-Butene Propyne	*	4.0	1.5	6.0	1.5	*
c-2-Butene	*	4.5	1.5	5.0	2.0	*
i-Pentane	11.5	31.5	10.5	126	16.0	4.0
n-Pentane	5.0	14.0	5.0	49.0	9.0	2.0
Cyclopentane	*	3.0	.5	6.0	.5	*
1-Pentene	.5	1.5	*	3.0	3.0	*
i-Hexane	2.0	9.5	2.5	24.5	10.0	1.0
3-Methylpentane	2.5	3.5	1.5	18.5	3.0	*
n-Hexane	2.0	5.0	1.5	14.5	3.0	.5
Cyclohexane	*	1.5	.5	3.0	*	.5
Total $\mu g/m^3$	68.0	182	104	541	113	39.5
NMTHC (ppm)	.6	.1		.7	.7	.1
CO (ppm)	1.2	1.3		1.3	1.4	1.3
CH_4 (ppm)	1.6	1.6		1.6	1.6	1.6
NO_x (ppb)						20


A-4
A-8
A-5
A-3
A-7
G-2, A-2
A-6
G-4
G-1
A-1
G-3
refinery
Sullivan
VINCENNES
St Francisville
Scale
1" = 13 mi.

BAG	LOCATION
G-1	Morn, 5 mile downwind
G-2	Morn, 10 mile downwind
G-3	Aft, tank farm, west of refinery
G-4	Aft, intown (corner 15th & State)
A-1	Morn, 5 mile downwind, 500'
A-2	Morn, 10 mile downwind, 500'
A-3	Morn, 15 mile downwind, 500'
A-4	Morn, 20 mile downwind, 500'
A-5	Morn, 20 mile downwind, 500'
A-6	Aft, 10 mile downwind, 1000'
A-7	Aft, 16 mile downwind, 1000'
A-8	Aft, 30 mile downwind, 1000'

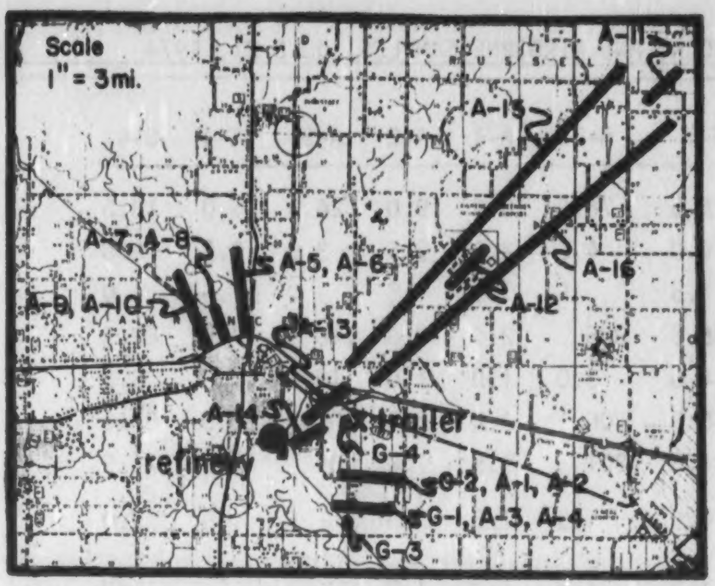
Figure A-7. Location of Hydrocarbon Samples Collected on June 20, 1974.

TABLE A-7. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 20, 1974

	G-1	G-2	A-1	A-2	A-3	A-5	A-4
Ethane	12.5	10.5	13.5	13.0	14.5	10.5	10.5
Ethylene	4.5	6.5	5.0	4.0	5.5	6.0	8.5
Acetylene	*	*	*	.5	1.0	.5	1.5
Propane	27.5	9.5	34.5	24.0	32.5	21.5	14.0
Propene	4.5	.5	11.5	2.5	4.5	3.0	5.5
i-Butane	15.5	3.5	23.0	10.5	14.5	9.5	7.0
n-Butane	26.5	7.0	35.5	22.5	28.0	17.0	12.0
neo-Pentane 1-Butene	1.5	*	.5	4.0	4.0	*	*
i-Butene	3.5	*	1.0	6.0	1.5	.5	*
t-2-Butene Propyne	1.0	*	*	2.0		*	
c-2-Butene		*	*	1.5		*	*
i-Pentane	11.0	3.0	12.0	12.0	19.5	8.5	7.0
n-Pentane	6.0	2.5	8.0	6.5	10.0	6.0	4.0
Cyclopentane	.5	*	*	.5	3.5	*	1.0
1-Pentene	*	*	1.0	.5	2.5	.5	*
i-Hexane	2.5	.5	3.5	3.0	4.5	2.5	2.0
3-Methylpentane	1.5	1.0	3.0	1.5	2.5	2.5	.5
n-Hexane	3.5	*	3.5	2.5	3.5	3.5	1.0
Cyclohexane	1.5	*	*	1.0	1.5	.5	*
Total $\mu g/m^3$	124	44.5	156	118	154	92.5	74.5
NMTHC (ppm)	.3	.2	.6	.6	.7	.4	.5
CO (ppm)	1.2	.9	1.8	1.6	1.9	2.0	1.6
CH_4 (ppm)	1.7	1.7	1.7	1.7	1.7	1.7	1.7
NO_x (ppb)	18	17					

TABLE A-7. (cont.)

	A-6	A-7	A-8	G-3	G-4
Ethane	8.5	6.5		52.5	8.5
Ethylene	8.0	3.5		6.0	7.0
Acetylene	.5	.5		*	.5
Propane	11.5	8.5		257	7.0
Propene	1.5	1.5		1.0	1.0
i-Butane	5.0	4.5		122	3.5
n-Butane	12.0	7.0		379	10.5
neo-Pentane 1-Butene	2.0			6.5	.5
i-Butene	1.5	*		4.5	.5
t-2-Butene Propyne	1.0	*		8.0	
c-2-Butene	1.5	*		7.5	.5
i-Pentane	9.0	4.5		206	8.0
n-Pentane	3.5	2.5		124	3.5
Cyclopentane	.5	*		10.5	.5
1-Pentene	*	*		3.0	*
i-Hexane	2.5	1.0		47.0	2.0
3-Methylpentane	1.5	.5		31.5	3.5
n-Hexane	1.5	*		41.0	1.5
Cyclohexane	.5	*			.5
Total $\mu g/m^3$	72.0	40.5		1307	59.0
NMTHC (ppm)	.3	.1	.1	3.1	.2
CO (ppm)	.9	.9	1.0	1.1	1.2
CH_4 (ppm)	1.6	1.6	1.6	1.6	1.6
NO_x (ppb)	20	18	16	16	18


Scale
1" = 3mi.
A-11
A-15
A-7, A-8
A-5, A-6
A-9, A-10
A-13
A-16
A-12
A-14
trailer
refinery
G-4
G-2, A-1, A-2
G-1, A-3, A-4
G-3

BAG	LOCATION
G-1	Morn, flare-side of plume, (under plane)
G-2	Morn, middle of plume
G-3	Morn, tank-side
G-4	Morn, taken from trailer manifold
A-1	Morn, flare-side, 1 mile, 500'
A-2	Morn, flare-side, 1 mile, 1000'
A-3	Morn, middle, 1 mile, 500'
A-4	Morn, middle, 1 mile, 1000'
A-5	Morn, flare-side, 2 mile, 500'
A-6	Morn, flare-side, 4 mile, 500'
A-7	Morn, middle, 1 mile, 500'
A-8	Morn, middle, 2 mile, 500'
A-9	Morn, tank-side, 2 mile, 500'
A-10	Morn, tank-side, 4 mile, 500'
A-11	Aft, 9-10 mile downwind, 1000'
A-12	Aft, 4-5 mile downwind, 1000'
A-13	Aft, 1-2 mile downwind, 1000'
A-14	Sample of flare @ 500'
A-15	Tank-side of plume, 1-8 mile integ, 1000'
A-16	Flare-side of plume, 1-8 mile integ, 1000'

Figure A-8. Location of Hydrocarbon Samples Collected on June 21, 1974.

TABLE A-8. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 21, 1974

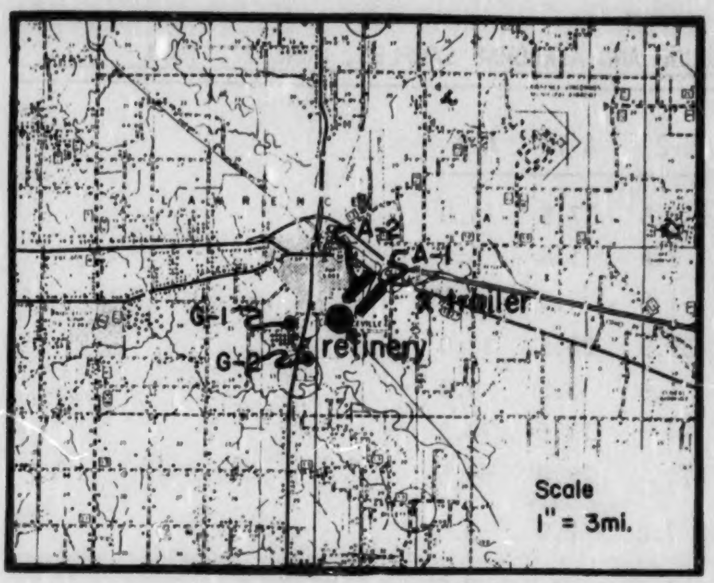
	G-1	G-2	G-3	A-1	A-2	A-3	A-4	G-4
Ethane	11.5	19.5	76.0	10.0	9.0	26.5	6.0	13.0
Ethylene	2.0	4.0	4.5	2.0	2.5	3.5	2.5	2.0
Acetylene	1.5	1.5	.5	1.0	.5	1.0	.5	1.0
Propane	16.0	66.5	606	12.0	10.0	110	7.5	82.5
Propene	1.0	4.0	3.0	1.0	1.0	19.0	1.5	8.5
i-Butane	3.5	58.0	206	3.0	3.5	103	2.5	53.0
n-Butane	11.0	84.5	801	9.5	7.0	104	6.0	70.5
neo-Pentane 1-Butene	.5	4.5	1.5	1.5	1.5	2.5	.5	2.0
i-Butene	*	4.5	1.0	1.0	1.0	2.5	*	2.0
t-2-Butene Propyne	.5	4.5	1.0	2.0	2.5	2.0	*	1.5
c-2-Butene	*	4.5	1.5	*	*	1.5	.5	1.0
i-Pentane	5.5	38.5	308	4.5	6.0	22.5	3.5	17.5
n-Pentane	4.0	13.0	416	2.5	2.5	12.5	2.0	12.5
Cyclopentane	.5	2.5	25.5	*	.5	2.5	*	3.5
1-Pentene	*	1.5	*	*	*	1.0	*	1.0
i-Hexane	3.0	9.0	104	1.5	2.0	6.0	.5	5.0
3-Methylpentane	1.5	5.0	66.5	1.0	*	4.0	*	5.5
n-Hexane	2.0	6.5	150	1.5	2.5	6.5	2.0	5.5
Cyclohexane	.5	2.0	34.0	*	*		*	*
Total $\mu g/m^3$	64.5	334	2806	54	52	431	35.5	288
NMTHC (ppm)	.3	.8	5.2	.4	.4	1.2	.4	
CO (ppm)	.8	.8	.7	.7	.7	1.8	.7	
CH_4 (ppm)	1.6	1.6	1.7	1.6	1.6	1.6	1.6	
NO_x (ppb)	16	16	15					

TABLE A-8. (cont.)

	A-5	A-6	A-9	A-10	A-7	A-8	A-14
Ethane	9.5	9.0	15.0	12.0	30.5	27.0	
Ethylene	3.0	4.0	4.5	4.5	10.5	5.5	
Acetylene	*	*	.5	.5	.5	.5	
Propane	13.5	12.0	37.5	25.5	120	99.5	
Propene	1.5	1.5	17.0	11.5	15.0	13.5	
i-Butane	4.0	4.0	18.0	8.0	70.0	58.0	
n-Butane	9.0	11.5	35.0	29.0	85.0	75.5	
neo-Pentane 1-Butene	1.5	2.0	3.5	1.5	5.0	4.0	
i-Butene	1.5		3.0	1.5	4.5	4.0	
t-2-Butene Propyne	3.0		1.5	.5	4.5	3.5	
c-2-Butene	*	*	1.0	.5	3.5	2.5	
i-Pentane	5.5	5.5	22.5	24.5	18.0	17.5	
n-Pentane	4.0	3.5	16.5	19.0	11.0	10.5	
Cyclopentane	.5	1.0	3.5	4.0	3.5	2.0	
1-Pentene	*	*	3.0	1.5		1.0	
i-Hexane	2.5	3.0	5.5	6.0	6.0	5.5	
3-Methylpentane	1.0	1.0	5.0	4.5	3.5	2.5	
n-Hexane	1.5	2.0	9.5	7.5	4.5	5.5	
Cyclohexane	*	.5	3.5	2.5	2.0	1.5	
Total μg/m^3	61.5	60.5	196	165	398	340	
NMTHC (ppm)	.3	.4		.5		.9	1.2
CO (ppm)	1.1	1.1		1.0		2.3	3.5
CH_4 (ppm)	1.6	1.6		1.6		1.6	1.6
NO_x (ppb)							24

TABLE A-8. (cont.)

	A-13	A-12	A-11	A-15	A-16
Ethane	11.5	13.5	13.5	9.5	8.5
Ethylene	6.5	8.0	4.5	10.5	17.0
Acetylene	1.0	.5	.5	.5	.5
Propane	33.0	43.0	56.0	12.5	11.0
Propene	3.0	9.0	12.5	2.0	2.0
i-Butane	14.5	22.5	34.0	7.5	8.0
n-Butane	26.0	37.0	52.5	13.5	13.0
neo-Pentane 1-Butene	2.5	1.0	1.5	1.0	*
i-Butene	1.5	1.0	1.5	1.0	2.0
t-2-Butene Propyne	1.5	.5	1.0	1.5	.5
c-2-Butene	*	*	1.0	.5	.5
i-Pentane	10.0	14.0	20.0	11.5	13.0
n-Pentane	5.5	9.0	11.5	4.5	5.0
Cyclopentane	.5	2.0	4.0	.5	
1-Pentene	.5	1.0	1.0	*	.5
i-Hexane	4.5	3.5	4.0	2.5	2.5
3-Methylpentane	2.0	3.0	3.5	2.0	2.0
n-Hexane	3.0	4.0	5.0	9.5	5.5
Cyclohexane	1.0	*	*	*	2.0
Total $\mu g/m^3$	128	173	228	90.0	94.0
NMTHC (ppm)	.5		.8	.4	.5
CO (ppm)	1.7		2.1	.8	1.1
CH_4 (ppm)	1.6		1.6	1.6	1.6
NO_x (ppb)				19	19

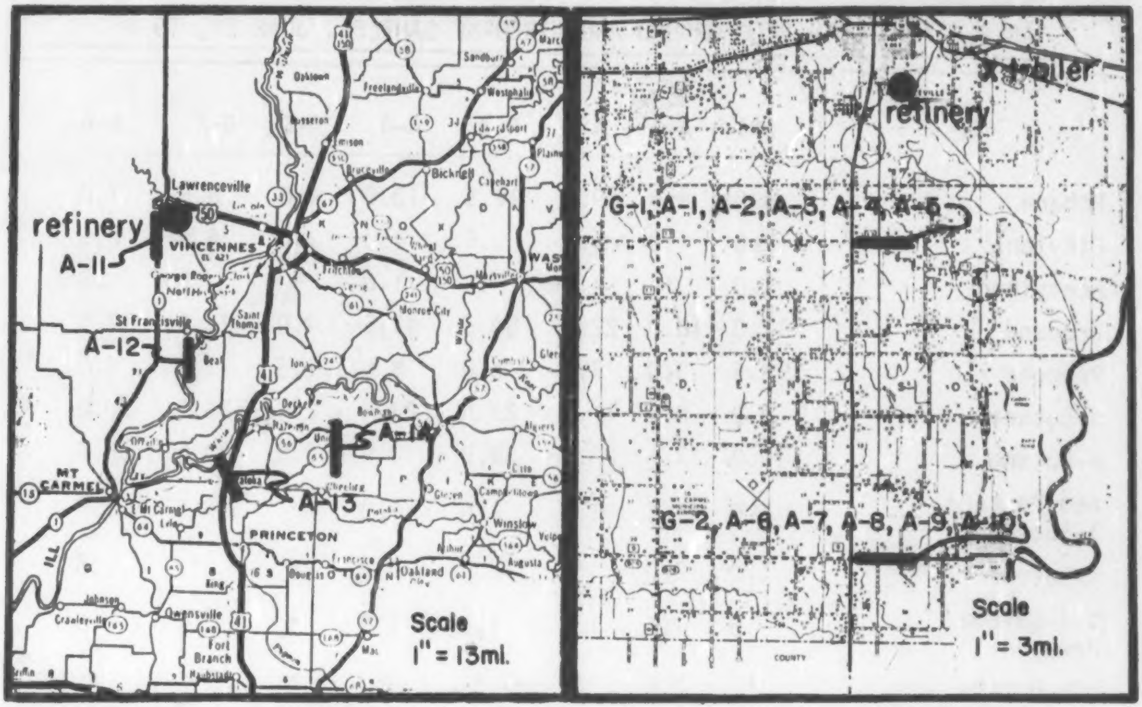

A-2
A-1
trailer
G-1
G-2
refinery
Scale
1" = 3mi.

BAG	LOCATION
G-1	Morn, tank farm, west of refinery
G-2	Morn, fenceline, south site
A-1	Morn, flare sample, 1000'
A-2	Morn, stack soot sample, 1000'

Figure A-9. Location of Hydrocarbon Samples Collected on June 22, 1974.

TABLE A-9. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 22, 1974

	G-1	G-2	A-1	A-2
Ethane	10.5	7.5	17.5	14.0
Ethylene	5.0	3.5	11.8	6.5
Acetylene	1.0	1.5	4.0	2.5
Propane	27.5	39.5	25.5	38.0
Propene	5.0	5.5	3.5	9.5
i-Butane	12.5	134	11.5	18.0
n-Butane	24.5	871	25.0	50.5
neo-Pentane 1-Butene	.5	7.0	2.0	3.0
i-Butene	.5	1.5	*	2.5
t-2-Butene Propyne	.5	1.5	1.5	1.5
c-2-Butene	*	*	.5	*
i-Pentane	10.5	852	14.0	30.5
n-Pentane	6.5	869	9.5	18.0
Cyclopentane	2.5	55.5	1.5	3.0
1-Pentene	*	2.0	*	2.0
i-Hexane	3.0	197	5.5	8.0
3-Methylpentane	16.0	120	2.5	6.0
n-Hexane	5.5	218	4.0	8.5
Cyclohexane	1.0	46.5	.5	*
Total $\mu g/m^3$	133	3433	140	222
NMTHC (ppm)	.4	6.0	.4	
CO (ppm)	.8	.9	.7	
CH_4 (ppm)	1.6	1.6	1.5	
NO_x (ppb)	15	22		


refinery
A-11
A-12
A-13
A-14
Lawrenceville
VINCENNES
St Francisville
MT CARMEL
PRINCETON
Scale
1" = 13mi.
X boiler
refinery
G-1, A-1, A-2, A-3, A-4, A-5
G-2, A-6, A-7, A-8, A-9, A-10
Scale
1" = 3mi.

BAG	LOCATION
G-1	Morn, 2 mile downwind
G-2	Morn, 8 mile downwind
A-1	Morn, 2 mile downwind, 500'
A-2	Morn, 2 mile downwind, 750'
A-3	Morn, 2 mile downwind, 1000'
A-4	Morn, 2 mile downwind, 1500'
A-5	Morn, 2 mile downwind, 2000'
A-6	Morn, 8 mile downwind, 500'
A-7	Morn, 8 mile downwind, 750'
A-8	Morn, 8 mile downwind, 1000'
A-9	Morn, 8 mile downwind, 1500'
A-10	Morn, 8 mile downwind, 2000'
A-11	Aft, 4 mile downwind, 1000'
A-12	Aft, 12 mile downwind, 1000'
A-13	Aft, 21 mile downwind, 1000'
A-14	Aft, clean air, 22 mile SE, 1000'

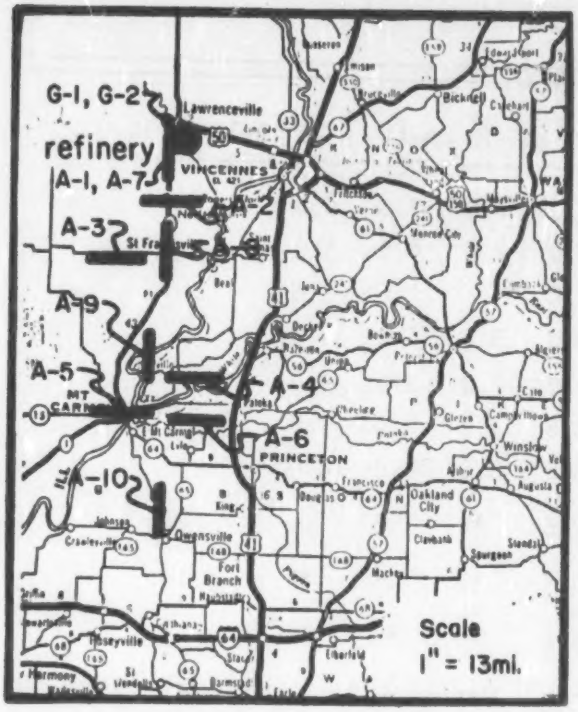
Figure A-10. Location of Hydrocarbon Samples Collected on June 23, 1974.

TABLE A-10. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 23, 1974

	G-1	A-1	A-2	A-3	A-4	A-5	G-2	A-6
Ethane	8.5	8.5	9.0	12.5	13.0	6.0	8.5	7.0
Ethylene	2.0	4.0	4.0	5.5	4.0	3.0	4.0	2.5
Acetylene	1.0	*	.5	*	1.0	*	.5	.5
Propane	17.0	18.0	22.5	50.5	41.5	4.0	23.0	17.5
Propene	5.5	3.0	3.5	5.0	5.0	1.5	3.5	4.0
i-Butane	9.0	8.0	11.5	29.5	28.5	2.5	54.0	39.0
n-Butane	19.0	17.5	23.0	39.0	50.0	9.5	30.0	30.5
neo-Pentane 1-Butene	1.5	1.5	1.0	2.0	1.0	*	.5	1.0
i-Butene	1.0	2.0	*	2.0	1.5	*	*	.5
t-2-Butene Propyne	.5	1.5	1.5	1.0	1.0	*	.5	.5
c-2-Butene	*	2.0	*	*	*	*	*	*
i-Pentane	13.0	11.0	8.5	16.5	37.0	7.5	9.0	19.0
n-Pentane	11.0	5.0	6.5	6.5	12.0	2.0	4.0	7.5
Cyclopentane	*	1.0	*	1.5	1.0	.5	1.0	1.0
1-Pentene	1.0	.5	*	1.0	1.0	*	.5	1.0
i-Hexane	3.5	3.5	3.5	3.0	5.5	2.5	2.0	3.5
3-Methylpentane	2.0	1.5	1.5	2.0	4.5	1.0	1.0	2.0
n-Hexane	6.5	1.0	1.0	3.0	2.0	.5	3.0	3.5
Cyclohexane	2.0	.5	1.0	*	*	*	*	*
Total $\mu g/m^3$	104	90	99	181	210	40.5	145	141
NMTHC (ppm)	.4	.5	.5	.8	.8	.5	.4	.8
CO (ppm)	1.0	1.1	1.5	1.3	1.5	1.0	1.0	1.4
CH_4 (ppm)	1.6	1.6	1.6	1.6	1.7	1.6	1.7	1.6
NO_x (ppb)	22						14	

TABLE A-10. (cont.)

	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14
Ethane	11.0	9.5	9.0	3.5	7.0	5.5		
Ethylene	7.5	9.0	9.0	7.0	4.5	5.0		
Acetylene	1.0	1.0	1.0	.5	.5	.5		
Propane	29.5	16.5	18.0	3.0	14.5	4.0		
Propene	6.0	2.0	3.0	2.0	3.0	1.0		
i-Butane	95.5	38.0	54.5	1.0	8.0	2.0		
n-Butane	52.5	26.5	68.5	5.0	14.0	8.0		
neo-Pentane 1-Butene	4.5	3.0	2.5	*	1.5	.5		
i-Butene	3.5	3.5	4.5	*	.5	*		
t-2-Butene Propyne	3.5	3.5	5.0	*	*	*		
c-2-Butene	2.5	1.5	3.5	*	*	*		
i-Pentane	19.5	17.0	47.5	10.0	7.0	5.5		
n-Pentane	7.0	6.0	15.5	2.0	3.5	2.0		
Cyclopentane	2.0	1.0	2.5	*	*	*		
1-Pentene	*	*	3.5	*	*	*		
i-Hexane	4.0	4.0	10.0	1.5	1.0	1.5		
3-Methylpentane	2.0	2.0	6.5	.5	*	.5		
n-Hexane	1.5	2.0	3.5	*	.5	1.0		
Cyclohexane	*	.5	1.5	*	*	*		
Total $\mu g/m^3$	253	147	269	36	65.5	37		
NMTHC (ppm)	.8		1.0	.6	.4	.3	.2	.2
CO (ppm)	1.4		1.1	.8	1.0	1.0	.7	.8
CH_4 (ppm)	1.7		1.6	1.7	1.6	1.6	1.6	1.7
NO_x (ppb)					9	7	9	7


G-1, G-2
refinery
A-1, A-7
A-2
A-3
A-8
A-9
A-5
A-4
A-6
A-10
Lawrenceville
VINCENNES
Bicknell
MT CARMEL
PRINCETON
Oakland City
Owensville
Fort Branch
Scale
1" = 13mi.

BAG	LOCATION
G-1	Morn, tank farm, west of refinery
G-2	Morn, fenceline, south site
A-1	Morn, 1 mile downwind, 1000'
A-2	Morn, 5 mile downwind, 1000'
A-3	Morn, 10 mile downwind, 1000'
A-4	Morn, 20 mile downwind, 1000'
A-5	Morn, 25 mile downwind, 1000'
A-6	Morn, 25 mile downwind, 1000'
A-7	Aft, 2 mile downwind, 1000'
A-8	Aft, 8 mile downwind, 1000'
A-9	Aft, 16 mile downwind, 1000'
A-10	Aft, 28 mile downwind, 1000'

Figure A-11. Location of Hydrocarbon Samples Collected on June 24, 1974.

TABLE A-11. DATA FROM GROUND AND AIRBORNE SAMPLES, JUNE 24, 1974

	A-1	A-2	A-3	A-4	A-5	A-6	G-1
Ethane	8.5	14.5	9.5	9.0	11.5	9.0	7.0
Ethylene	3.0	3.5	5.0	7.0	2.0	4.0	10.5
Acetylene	*	1.0	*	*	1.0	1.0	2.5
Propane	25.5	49.0	23.0	17.5	22.0	17.0	5.0
Propene	3.5	2.5	3.5	3.5	1.0	1.0	5.0
i-Butane	18.5	26.5	16.0	13.0	7.5	7.0	4.5
n-Butane	36.5	57.0	33.0		21.5	17.0	19.0
neo-Pentane 1-Butene	1.0	3.5	1.0		1.5	1.5	1.0
i-Butene	1.0	2.5	.5		1.0	1.5	1.0
t-2-Butene Propyne	1.0	3.0	1.0		1.5	1.5	1.5
c-2-Butene	1.0	2.0	1.0		1.0	1.5	*
i-Pentane	20.0	27.5	19.5	20.5	9.0	9.0	25.0
n-Pentane	10.5	13.0	9.5	9.0	5.5	4.0	16.0
Cyclopentane	2.0	1.5	*	1.5	1.0	1.0	3.0
1-Pentene	1.0	.5		1.0	*	*	1.5
i-Hexane	4.0	6.0	5.0	4.0	2.5	3.0	12.5
3-Methylpentane	3.5	3.5	2.5	2.0	1.5	1.5	9.0
n-Hexane	3.5	2.5	4.0	3.0	1.5	1.0	13.5
Cyclohexane	*	1.0	*	1.0	.5	*	5.0
Total $\mu g/m^3$	144	221	134		93	82	143
NMTHC (ppm)	.5	.6	.3	.5	.3	.3	.6
CO (ppm)	1.3	1.3	.9	1.2	.9	.9	1.8
CH_4 (ppm)	1.6	1.7	1.9	1.7	1.7	1.7	1.7
NO_x (ppb)	26		8	9			37

TABLE A-11. (cont.)

	G-2	A-7	A-8	A-9	A-10
Ethane	7.0	14.0	8.0	6.0	7.0
Ethylene	4.5	3.5	4.0	5.5	7.0
Acetylene	1.5	.5	.5	.5	*
Propane	5.5	47.0	13.5	6.5	6.0
Propene	2.0	6.0	2.0	1.5	2.5
i-Butane	35	31.0	7.0	4.0	4.0
n-Butane	9.0	54.0	18.0	11.0	11.0
neo-Pentane 1-Butene	2.5	1.5	2.0	.5	3.0
i-Butene	3.0	1.5	1.5	*	*
t-2-Butene Propyne		1.5	2.0	.5	1.0
c-2-Butene		1.0	1.5	*	*
i-Pentane	8.0	14.5	8.0	9.0	7.0
n-Pentane	3.5	7.0	4.0	4.0	4.0
Cyclopentane	1.0	*	*	*	.5
1-Pentene	*	1.0	*	*	*
i-Hexane	3.0	4.0	2.5	.5	3.5
3-Methylpentane	1.5	6.0	1.0	.5	1.0
n-Hexane	1.5	4.0	1.5	*	1.0
Cyclohexane	.5	*	.5	*	1.0
Total $\mu g/m^3$	89	198	77.5	50	59.5
NMTHC (ppm)	.4	.6	.3	.4	.3
CO (ppm)	1.0	3.2	1.7	1.5	1.6
CH_4 (ppm)	1.8	1.7	1.7	1.6	1.7
NO_x (ppb)	30				

APPENDIX B

Ozone, nitric oxide, nitrogen dioxide, non-methane total hydrocarbon, carbon monoxide and methane concentrations are listed in this appendix. Meteorological parameters including wind speed, wind direction, temperature, dew point and solar radiation are also tabulated. The data are compiled on a daily basis and recorded as hourly averages. Time is Central Daylight Time.

TABLE B-1. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 13

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	4	12	27	1.1	.9	2.0	1	290	12.9	9.7	0
0200	14	9	12	.8	.7	1.9	1	260	12.1	8.8	0
0300	20	6	11	.7	.7	1.9	1	170	11.1	8.3	0
0400	14	9	6	.7	.7	2.0	1	160	11.7	7.3	0
0500	12	9	11	.9	.7	2.0	1	130	11.4	8.4	0
0600	8	10	10	.8	.7	2.1	1	140	12.5	9.5	43
0700	8	12	11	.5	.7	2.0	2	150	14.5	14.5	183
0800	29	10	12	.2	.7	1.7	4	200	16.4	13.2	391
0900	40	11	8	.1	.7	1.6	3	200	23.6	12.9	779
1000	50	10	6	.2	.7	1.6	3	210	26.2	11.2	1040
1100	57	8	6	.1	.7	1.6	3	230	27.3	10.3	1027
1200	60	9	7	.1	.7	1.6	5	275	27.3	11.1	1065
1300	62	10	5	.1	.7	1.6	2	240	26.9	10.8	983
1400	61	10	4	.1	.7	1.6	3	230	29.3	10.5	1191
1500	57	9	4	.1	.6	1.6	1	240	26.5	10.3	798
1600	55	10	4	.1	.6	1.6	6	230	29.7	11.8	713
1700	55	10	4	.1	.6	1.6	3	260	28.2	11.6	756
1800	48	10	6	.1	.6	1.6	2	200	27.7	11.8	532
1900	54	11	5	.1	.6	1.6	3	220	25.2	11.7	407
2000	50	10	6	.1	.7	1.6	3	190	22.5	12.2	145
2100	55	9	7	.1	.7	1.7	2	180	21.2	11.2	43
2200	48	10	15	.1	.7	1.6	1	200	20.2	11.4	0
2300	49	9	13	.1	.7	1.6	4	190	19.2	10.8	0
2400	49	9	11	.1	.7	1.6	2	180	17.9	10.5	0

TABLE B-2 SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 14

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	41	9	12	.1	.7	1.7	1	200	16.3	9.9	0
0200	49	9	13	.2	.7	1.7	2	200	17.0	10.0	0
0300	41	9	12	.2	.7	1.7	2	170	15.7	5.7	0
0400	34	9	10	.1	.7	1.7	1	200	15.8	10.2	0
0500	-	9	10	.1	.7	1.7	2	190	16.1	10.3	0
0600	18	9	11	.1	.7	1.7	2	160	-	10.4	18
0700	29	12	11	.1	.7	1.7	1	170	19.2	12.8	173
0800	32	16	30	.2	.8	1.7	5	030	20.0	12.2	291
0900	35	10	18	.1	.8	1.7	9	350	18.2	12.1	78
1000	40	10	11	.1	.8	1.7	8	170	17.0	13.0	58
1100	45	11	11	.1	.8	1.7	9	170	19.9	15.3	303
1200	56	11	8	.1	.8	1.6	7	200	24.4	17.7	1184
1300	67	11	9	.1	.8	1.6	6	210	26.8	18.2	1154
1400	74	11	11	.1	.8	1.6	5	190	27.4	18.1	925
1500	80	12	10	.1	.8	1.6	5	210	30.4	19.2	1130
1600	64	11	7	.1	.7	1.6	13	200	26.2	16.7	908
1700	66	11	7	-	.7	1.6	7	170	22.9	17.0	157
1800	54	11	11	.1	.7	1.6	15	270	19.8	15.3	57
1900	38	13	14	.1	.8	1.6	6	160	20.2	16.7	70
2000	39	14	7	.1	.7	1.6	5	190	19.8	16.5	51
2100	34	13	8	.2	.7	1.6	8	180	19.6	16.4	41
2200	41	13	8	.2	.8	1.6	5	200	19.4	16.5	0
2300	51	12	7	.2	.8	1.6	5	230	19.3	16.3	0
2400	42	13	12	.3	.8	1.6	7	300	19.7	15.4	0

TABLE B-3. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 15

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	30	12	16	.9	1.0	1.5	15	250	18.9	13.3	0
0200	38	10	3	.1	.6	1.5	18	200	17.5	12.3	0
0300	35	10	4	.1	.6	1.5	6	080	17.8	13.3	0
0400	28	10	5	.1	.7	1.5	5	020	17.2	12.6	0
0500	-	11	9	.2	.7	1.6	5	280	16.3	12.0	0
0600	27	12	11	.7	1.3	1.6	3	260	17.2	13.0	8
0700	28	14	6	.3	.7	1.6	5	270	17.9	13.1	162
0800	19	22	24	.7	.9	1.6	5	260	20.0	13.7	329
0900	31	15	14	.6	1.3	1.6	7	260	22.6	15.2	734
1000	41	17	4	.8	.7	1.6	12	280	23.7	16.0	937
1100	46	19	5	.1	.7	1.6	10	280	25.5	17.1	1015
1200	47	16	7	.1	.7	1.6	10	280	25.9	15.0	1053
1300	47	10	4	.1	.7	1.6	15	290	27.2	10.9	1608
1400	46	9	4	.1	.7	1.6	14	290	27.7	10.7	1599
1500	47	8	4	.1	.7	1.6	14	280	28.2	9.0	1461
1600	45	8	4	.1	.7	1.6	14	290	28.4	9.1	1296
1700	49	9	4	.1	.6	1.6	12	280	28.1	9.5	1078
1800	44	10	5	.1	.7	1.6	9	280	28.1	10.2	780
1900	46	10	6	.1	.7	1.6	9	280	25.3	10.1	411
2000	42	9	7	.1	.7	1.5	17	310	23.5	10.7	108
2100	37	9	7	.1	.7	1.5	8	300	21.5	9.4	36
2200	34	10	8	.1	.7	1.5	8	300	20.2	9.2	0
2300	27	10	11	.1	.7	1.6	5	290	17.8	9.6	0
2400	15	8	26	.2	.9	1.7	5	270	16.2	8.5	0

TABLE B-4. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 16

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	22	9	8	.6	.7	1.7	5	240	15.2	8.7	0
0200	23	9	9	.4	.9	1.6	6	230	14.5	8.3	0
0300	21	9	6	.1	.7	1.6	9	270	15.3	7.5	0
0400	22	9	4	.1	.7	1.6	8	280	14.4	6.8	0
0500	-	8	7	.1	.7	1.6	9	280	13.4	6.2	0
0600	18	8	6	.1	.7	1.6	10	280	13.1	5.8	14
0700	18	9	7	.1	.7	1.6	12	280	13.6	6.0	106
0800	21	9	4	.2	.7	1.6	14	290	14.8	6.5	324
0900	23	9	3	.1	.7	1.6	12	290	16.4	7.5	611
1000	27	8	3	.1	.6	1.6	12	290	17.7	7.5	997
1100	29	6	4	.1	.6	1.6	14	290	17.2	5.3	838
1200	26	8	12	.1	.6	1.6	12	280	18.7	6.4	1038
1300	26	8	3	.1	.7	1.6	12	300	17.6	6.5	706
1400	30	7	3	.1	.6	1.6	12	290	18.4	6.8	692
1500	28	8	4	.1	.6	1.6	12	290	17.5	6.6	523
1600	31	8	4	.1	.6	1.6	10	280	19.0	6.7	637
1700	32	8	6	.1	.6	1.6	14	290	18.9	6.0	769
1800	29	9	6	.1	.6	1.6	10	280	18.4	6.3	530
1900	29	8	8	.1	.7	1.6	9	280	17.2	5.8	477
2000	16	9	19	.1	.7	1.6	3	310	14.8	6.5	114
2100	12	9	15	.2	.9	1.7	1	250	12.7	7.1	22
2200	12	9	14	.5	.8	1.7	2	240	12.7	6.7	0
2300	16	9	6	.4	.7	1.7	2	240	12.1	6.6	0
2400	15	10	8	.6	.7	1.7	2	240	11.1	6.3	0

TABLE B-5. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 17

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	12	11	15	.7	.7	1.7	2	250	13.1	6.9	0
0200	17	10	7	.3	.7	1.7	3	270	13.3	6.7	0
0300	14	10	10	.4	.7	1.7	1	230	13.0	6.3	0
0400	14	16	15	.7	.7	1.7	3	270	12.7	6.4	0
0500	-	11	7	.3	.7	1.7	1	250	11.9	6.5	0
0600	16	11	5	.3	.7	1.7	3	230	12.0	7.6	16
0700	17	11	6	.3	.7	1.7	1	210	14.9	9.0	117
0800	20	12	6	.2	.6	1.6	2	240	17.3	9.7	253
0900	20	10	3	.1	.6	1.6	2	240	18.2	9.1	426
1000	26	10	5	.1	.6	1.6	3	210	20.2	8.7	568
1100	29	10	3	.1	.6	1.6	2	270	20.4	8.5	609
1200	35	10	7	.1	.7	1.6	3	210	23.2	9.9	796
1300	36	10	4	.2	.9	1.6	4	250	21.7	9.7	659
1400	41	10	4	.1	.7	1.6	7	280	22.5	10.0	1053
1500	43	9	4	.1	.7	1.6	9	280	22.9	9.1	1138
1600	39	9	3	.1	.7	1.6	7	270	23.0	8.4	1405
1700	42	8	3	.1	.7	1.6	10	290	23.3	8.4	839
1800	44	8	3	.1	.6	1.6	8	270	22.6	7.9	759
1900	44	19	3	.1	.6	1.6	2	260	21.2	7.9	459
2000	27	10	12	.2	.8	1.6	1	290	18.1	8.6	120
2100	18	13	28	.7	2.0	1.6	CALM		14.8	8.1	8
2200	14	14	12	.3	1.2	1.6	2	110	13.6	8.9	0
2300	15	14	7	.2	.7	1.7	1	130	12.6	8.6	0
2400	20	13	10	.3	.8	1.7	2	160	12.2	8.3	0

TABLE B-6. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 18

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	17	21	8	.4	.7	1.7	3	170	11.9	7.9	0
0200	16	20	10	.4	.7	1.7	4	170	11.8	7.8	0
0300	16	20	9	.4	.7	1.7	3	170	12.6	8.4	0
0400	18	19	9	.2	.7	1.7	3	180	12.6	8.2	0
0500	17	19	7	.2	.7	1.7	4	160	12.1	7.5	0
0600	13	20	6	.2	.7	1.7	3	160	12.4	7.8	9
0700	23	23	8	.3	.7	1.7	1	180	15.6	10.5	161
0800	31	23	8	.2	.7	1.7	6	190	19.8	12.1	352
0900	44	21	6	.2	.7	1.7	6	200	23.9	13.4	757
1000	54	21	5	.4	1.0	1.6	6	200	27.1	14.3	1017
1100	60	21	4	.2	.7	1.6	12	190	29.2	14.5	1207
1200	53	21	2	.1	.7	1.6	9	200	29.7	13.6	1253
1300	61	20	3	.2	.7	1.6	9	190	29.3	12.7	1413
1400	65	20	3	.1	.7	1.6	12	200	31.3	12.9	1425
1500	58	19	3	.1	.7	1.6	9	200	32.1	12.2	1351
1600	60	20	3	.1	.7	1.6	8	220	31.1	12.9	1229
1700	66	20	3	.1	.7	1.6	10	210	32.0	13.1	869
1800	63	22	4	.1	.7	1.6	12	200	30.4	14.1	730
1900	58	25	4	.1	.7	1.6	9	200	27.1	15.2	349
2000	54	26	4	.1	.7	1.6	7	190	24.8	15.4	83
2100	48	27	5	.1	.7	1.6	7	170	23.6	15.8	11
2200	44	27	5	.1	.7	1.6	8	180	22.2	15.6	0
2300	40	27	5	.1	.7	1.6	6	180	22.4	16.0	0
2400	39	28	5	.1	.7	1.6	9	170	22.9	16.0	0

TABLE B-7. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 19

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	40	27	7	.1	.7	1.6	8	160	22.6	15.8	0
0200	39	27	5	.1	.7	1.6	14	180	22.8	15.8	0
0300	39	27	5	.1	.7	1.6	14	190	22.8	15.8	0
0400	35	27	5	.1	.7	1.6	13	190	22.1	15.7	0
0500	33	27	6	.1	.7	1.6	10	190	22.1	15.9	0
0600	30	26	6	.1	.7	1.6	12	180	22.2	16.1	0
0700	32	24	6	.2	.7	1.6	6	290	19.3	14.5	30
0800	29	23	4	.1	.7	1.6	13	180	18.8	14.3	32
0900	31	15	4	.1	.7	1.6	16	160	18.8	14.2	73
1000	29	19	3	.1	.7	1.6	9	200	20.9	17.2	307
1100	33	20	14	.1	.6	1.6	12	210	23.4	18.7	692
1200	36	20	3	.1	.6	1.6	12	220	25.4	18.9	899
1300	38	21	3	.1	.6	1.6	6	210	28.3	18.9	1236
1400	40	20	2	.1	.7	1.6	6	240	31.4	19.6	1346
1500	42	23	1	.1	.6	1.6	10	240	31.8	19.0	1311
1600	45	20	2	.1	.6	1.6	13	210	33.0	20.1	1163
1700	56	20	3	.1	.6	1.6	12	210	33.4	20.5	977
1800	56	20	4	.1	.7	1.6	15	210	32.2	19.7	735
1900	57	21	4	.1	.7	1.6	8	220	30.9	20.2	423
2000	48	18	10	.1	.7	1.6	2	210	26.3	19.5	132
2100	43	19	3	.2	.7	1.7	5	210	24.2	18.9	16
2200	27	19	19	.3	.7	1.7	CALM		24.2	18.9	0
2300	23	18	10	.1	.8	1.7	2	110	24.0	18.9	0
2400	35	12	5	.1	.6	1.6	3	150	21.3	16.1	0

TABLE B-8. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 20

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	30	11	5	.1	.6	1.6	8	150	20.4	15.7	0
0200	30	9	5	.1	.6	1.6	15	210	20.1	15.8	0
0300	29	8	3	.1	.6	1.6	8	230	19.9	15.0	0
0400	27	7	3	.1	.6	1.6	7	200	19.6	14.6	0
0500	23	7	4	.1	.6	1.6	5	200	19.6	14.6	0
0600	22	9	3	.1	.6	1.6	6	180	19.9	15.1	5
0700	25	10	5	.1	.7	1.7	3	200	22.0	16.5	139
0800	28	14	7	.1	.7	1.7	8	200	25.6	19.4	344
0900	35	-	-	.1	.7	1.7	7	220	28.9	21.3	669
1000	44	24	6	.1	.7	1.7	8	220	31.1	22.5	865
1100	47	25	5	.1	.7	1.7	6	230	32.2	23.1	1143
1200	50	24	4	.1	.7	1.7	7	220	34.1	23.9	1455
1300	47	19	5	.1	.7	1.6	10	220	34.5	23.3	1464
1400	51	16	2	.1	.7	1.6	9	210	35.6	23.5	1332
1500	54	15	3	.1	.7	1.6	10	210	36.5	23.5	1159
1600	59	14	4	.1	.7	1.6	8	220	37.3	23.6	1182
1700	60	14	4	.1	.7	1.6	9	220	36.6	23.2	914
1800	64	14	4	.1	.7	1.6	10	210	35.3	22.7	623
1900	60	15	4	.1	.7	1.6	10	210	32.7	21.5	389
2000	57	15	6	.3	.9	1.6	3	230	28.6	21.1	80
2100	41	13	8	.2	.7	1.6	19	270	25.6	17.6	0
2200	25	10	17	-	-	-	2	290	22.1	15.9	0
2300	31	10	5	-	-	-	12	330	21.3	15.7	0
2400	30	10	5	-	-	-	6	240	21.7	15.9	0

TABLE B-9. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 21

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	30	9	9	-	-	-	8	230	21.4	16.0	0
0200	34	9	3	-	-	-	16	200	20.6	15.7	0
0300	36	9	4	-	-	-	9	200	22.1	16.3	0
0400	35	8	3	-	-	-	10	210	23.9	15.8	0
0500	36	8	3	-	-	-	12	220	24.2	15.5	0
0600	34	8	4	-	-	-	6	180	22.6	15.2	2
0700	28	9	4	-	-	-	6	330	23.8	15.9	48
0800	27	9	10	.2	.8	1.6	3	260	23.7	16.3	121
0900	24	11	10	.1	.7	1.6	14	340	23.2	16.3	109
1000	29	11	5	.1	.6	1.6	10	140	24.4	17.5	228
1100	-	-	-	.1	.7	1.6	2	010	-	-	486
1200	39	13	5	.3	.7	1.6	3	160	28.6	20.0	665
1300	37	13	5	.2	.8	1.6	6	200	27.3	20.0	451
1400	47	15	10	.2	.8	1.6	5	250	30.8	21.0	1083
1500	52	16	4	.1	.7	1.6	14	220	28.6	20.5	663
1600	52	16	4	.1	.7	1.6	15	220	31.8	21.8	773
1700	54	15	3	.4	1.0	1.6	9	250	32.4	22.0	892
1800	49	14	4	.2	.7	1.6	9	240	32.9	21.2	692
1900	45	17	4	.2	.7	1.6	6	200	30.3	21.1	359
2000	22	18	31	.2	.9	1.6	1	050	27.2	20.6	73
2100	30	15	14	.1	.8	1.6	5	090	26.1	20.9	8
2200	23	15	20	.2	.9	1.6	3	180	25.2	20.5	0
2300	15	16	19	.3	.9	1.7	2	090	25.3	20.3	0
2400	17	15	11	.3	.9	1.7	2	170	24.8	20.2	0

TABLE B-10. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 22

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	40	10	4	.1	.6	1.5	29	320	19.3	13.7	0
0200	34	9	4	.3	.7	1.5	6	010	18.9	14.4	0
0300	22	8	6	.2	.7	1.5	CALM		19.0	14.7	0
0400	25	8	3	.6	.6	1.6	1	280	19.1	14.7	0
0500	24	8	3	.2	.6	1.5	CALM		19.3	15.2	0
0600	20	8	3	.1	.6	1.6	3	180	19.5	15.4	4
0700	25	9	3	.2	.6	1.5	3	170	20.2	16.0	106
0800	29	9	4	.1	.6	1.5	8	170	20.8	16.6	208
0900	23	10	8	.1	.6	1.6	8	070	21.7	16.7	167
1000	30	9	5	.1	.6	1.5	8	070	25.0	18.7	525
1100	-	-	-	.2	.9	1.6	23	160	-	-	486
1200	-	-	-	.1	.6	1.6	12	030	-	-	334
1300	30	11	5	.1	.6	1.5	12	070	25.1	18.5	438
1400	32	12	5	.1	.6	1.5	5	080	26.0	19.2	499
1500	40	14	4	.1	.7	1.6	7	160	29.2	21.2	1133
1600	44	13	3	.1	.7	1.6	14	210	31.6	21.6	846
1700	44	13	3	.1	.6	1.6	6	180	27.6	20.3	349
1800	-	-	-	-	-	-	2	260	-	-	26
1900	-	-	-	-	-	-	7	260	-	-	433
2000	19	6	21	.3	1.2	1.7	16	270	18.9	13.1	138
2100	26	6	11	.1	.9	1.6	14	280	18.6	13.0	29
2200	29	6	9	.1	.8	1.6	27	330	17.4	11.8	0
2300	27	5	7	.1	.7	1.6	21	330	16.8	11.4	0
2400	26	5	8	.1	.7	1.6	19	330	16.3	10.7	0

TABLE B-11. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 23

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	22	4	7	.1	.8	1.6	17	340	15.8	9.9	0
0200	18	4	8	.1	.9	1.6	18	330	15.0	8.7	0
0300	14	4	11	.2	.9	1.6	17	340	14.3	8.0	0
0400	9	4	13	.2	.9	1.6	15	340	13.9	8.0	0
0500	8	4	15	.1	.8	1.6	12	340	13.9	8.3	0
0600	10	6	13	.1	.8	1.6	12	330	13.7	8.3	7
0700	12	9	9	.1	.8	1.6	10	340	14.3	8.8	163
0800	13	10	8	.1	.8	1.6	14	350	15.9	9.2	334
0900	16	10	7	.1	.7	1.6	12	350	17.8	9.4	780
1000	18	10	8	-	-	-	14	360	19.4	9.9	1046
1100	22	9	17	.1	.7	1.6	15	340	20.8	10.4	1228
1200	33	7	12	.1	.6	1.6	16	340	21.9	10.0	1291
1300	34	7	4	.1	.6	1.6	17	350	22.5	9.3	1628
1400	36	6	4	.1	.6	1.6	18	350	22.5	8.8	1260
1500	33	6	5	.1	.6	1.6	19	360	22.0	8.9	1414
1600	33	6	6	.1	.6	1.6	17	350	21.6	8.2	803
1700	32	6	7	.1	.6	1.6	14	360	21.0	8.1	744
1800	27	7	9	.1	.6	1.6	14	340	20.3	8.1	395
1900	30	6	6	.1	.7	1.6	14	330	19.4	8.3	449
2000	31	6	5	.1	.8	1.6	10	330	17.0	8.0	107
2100	28	6	7	.1	.7	1.6	10	330	15.5	8.0	12
2200	27	7	6	.1	.7	1.6	12	340	14.8	8.2	0
2300	19	8	12	.1	.7	1.6	12	350	13.9	7.9	0
2400	17	8	10	.1	.7	1.6	14	360	13.2	7.5	0

TABLE B-12. SURFACE MEASUREMENTS AT LAWRENCEVILLE, ILLINOIS ON JUNE 24

TIME hrs.	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppm	CO ppm	CH_4 ppm	W S mph	W D deg	T °c	DP °c	RAD mLy
0100	16	9	9	.1	.7	1.6	13	360	12.5	6.8	0
0200	13	9	9	.1	.7	1.6	11	360	11.3	6.4	0
0300	12	10	9	.1	.7	1.6	11	360	10.7	6.0	0
0400	7	11	14	.1	.7	1.7	7	350	10.0	5.7	0
0500	5	13	15	.1	.7	1.7	2	340	9.6	5.5	0
0600	5	17	16	.1	.7	1.7	5	340	9.7	5.6	0
0700	6	21	13	.1	.8	1.7	6	340	10.8	6.9	90
0800	7	19	11	.1	.9	1.7	8	350	13.5	8.1	256
0900	9	21	11	.1	.8	1.7	9	340	15.7	8.6	415
1000	10	26	14	.1	.8	1.7	10	350	17.7	9.4	663
1100	22	11	7	.1	.7	1.6	14	010	18.3	9.0	633
1200	22	9	10	.1	.7	1.6	14	350	19.1	7.8	1100
1300	30	6	6	.1	.7	1.6	15	010	21.0	8.8	1304
1400	33	6	7	.1	.7	1.6	15	350	21.9	9.2	985
1500	40	4	5	.1	.7	1.6	13	350	22.7	9.2	1114
1600	45	3	3	.1	.7	1.6	11	360	23.0	8.8	976
1700	46	3	3	.1	.7	1.6	11	350	23.4	9.0	1020
1800	42	4	16	.1	.7	1.6	13	350	22.7	8.9	711
1900	35	4	15	.1	.7	1.6	9	360	21.4	8.7	442
2000	37	3	11	.1	.7	1.6	8	330	18.5	8.6	106
2100	30	3	12	.1	.7	1.6	6	330	16.7	9.2	8
2200	28	4	11	.1	.7	1.6	6	330	15.5	9.3	0
2300	25	6	9	.1	.7	1.6	9	360	15.0	9.1	0
2400	22	9	9	.1	.7	1.6	9	360	14.1	8.5	0

APPENDIX C

Maps showing ozone survey flight paths are provided in this section. Ozone concentrations (ppb) are marked at points along the route.

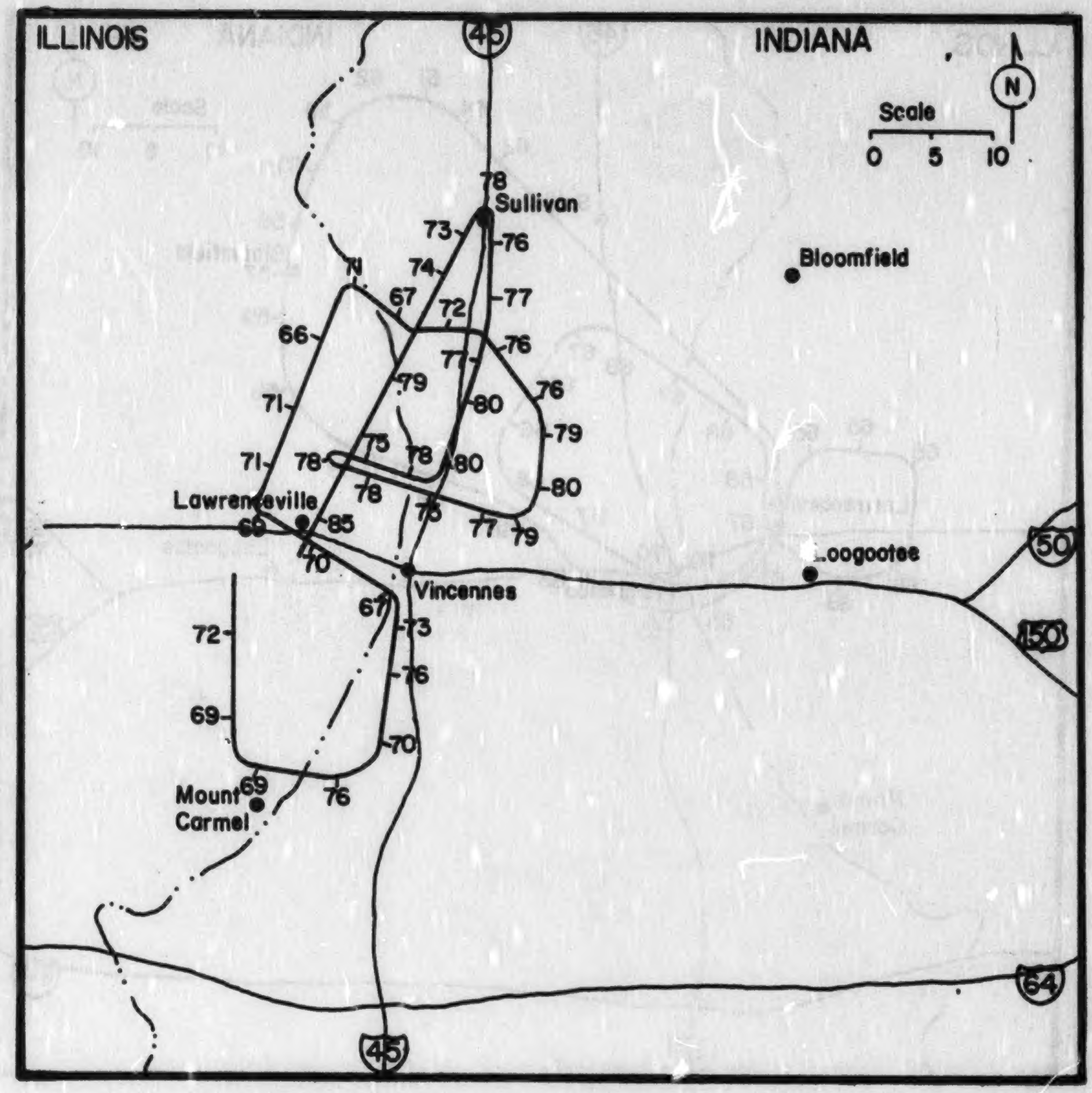

ILLINOIS
INDIANA
45
N
Scale
0 5 10
78
Sullivan
73
76
74
77
67
72
66
76
77
79
80
71
76
79
75
78
71
78
80
80
78
Lawrenceville
69
85
75
77
79
70
Vincennes
Loogootee
50
150
67
73
72
76
69
70
69
76
Mount Carmel
Bloomfield
64
45

Figure C-1. Ozone survey flight during afternoon hours on June 13. Winds varied between 180° and 200° at 5 mph.

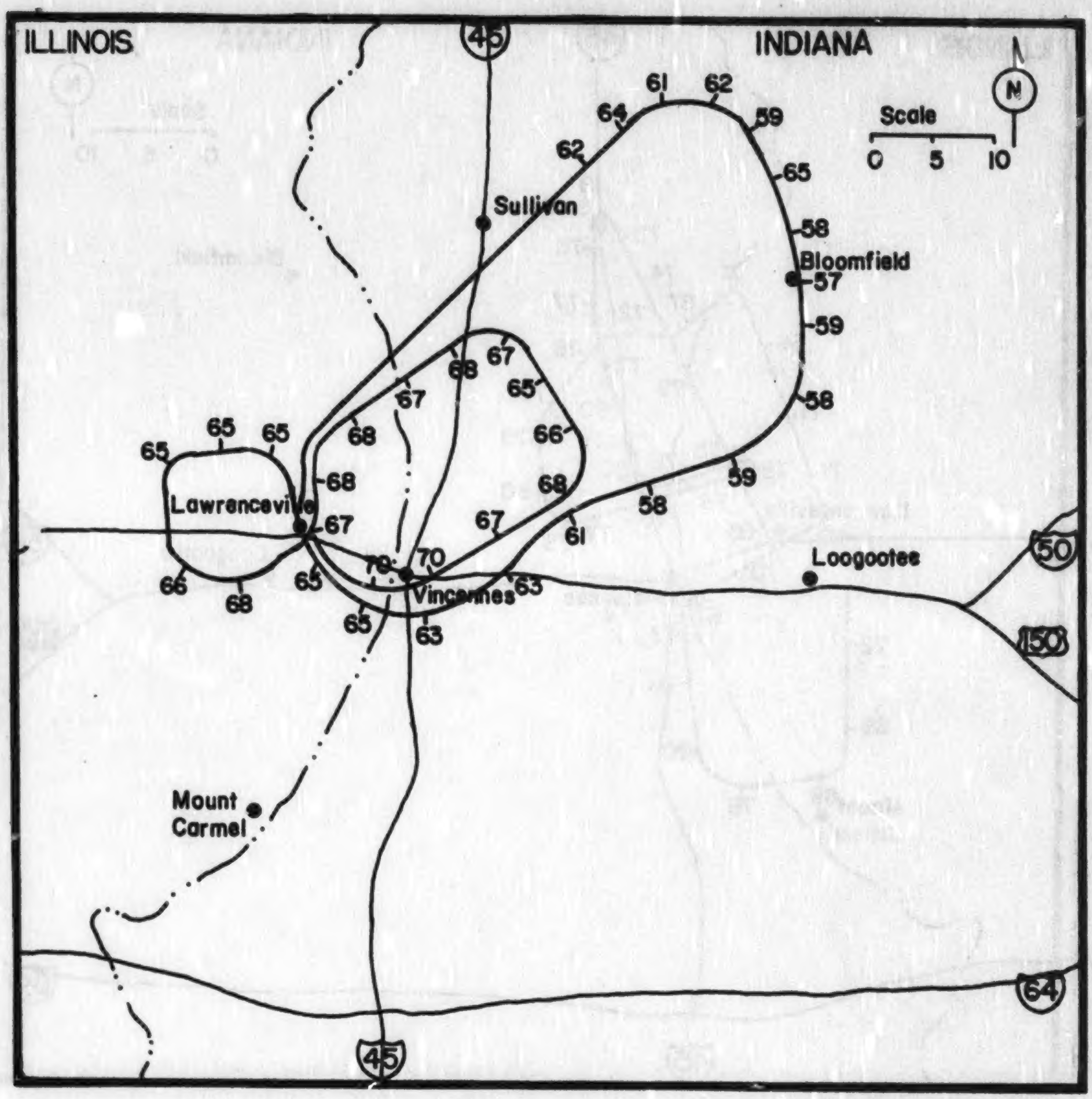

ILLINOIS
INDIANA
45
N
Scale
0 5 10
61
62
64
59
62
65
Sullivan
58
Bloomfield
57
59
67
68
65
58
67
65
65
65
68
66
68
Lawrenceville
67
68
67
61
58
59
70
70
66
68
65
Vincennes
63
65
63
Loogootee
50
150
Mount Carmel
64
45

Figure C-2. Ozone survey flight during afternoon hours on June 20. Wind direction was 220° at 8 mph.

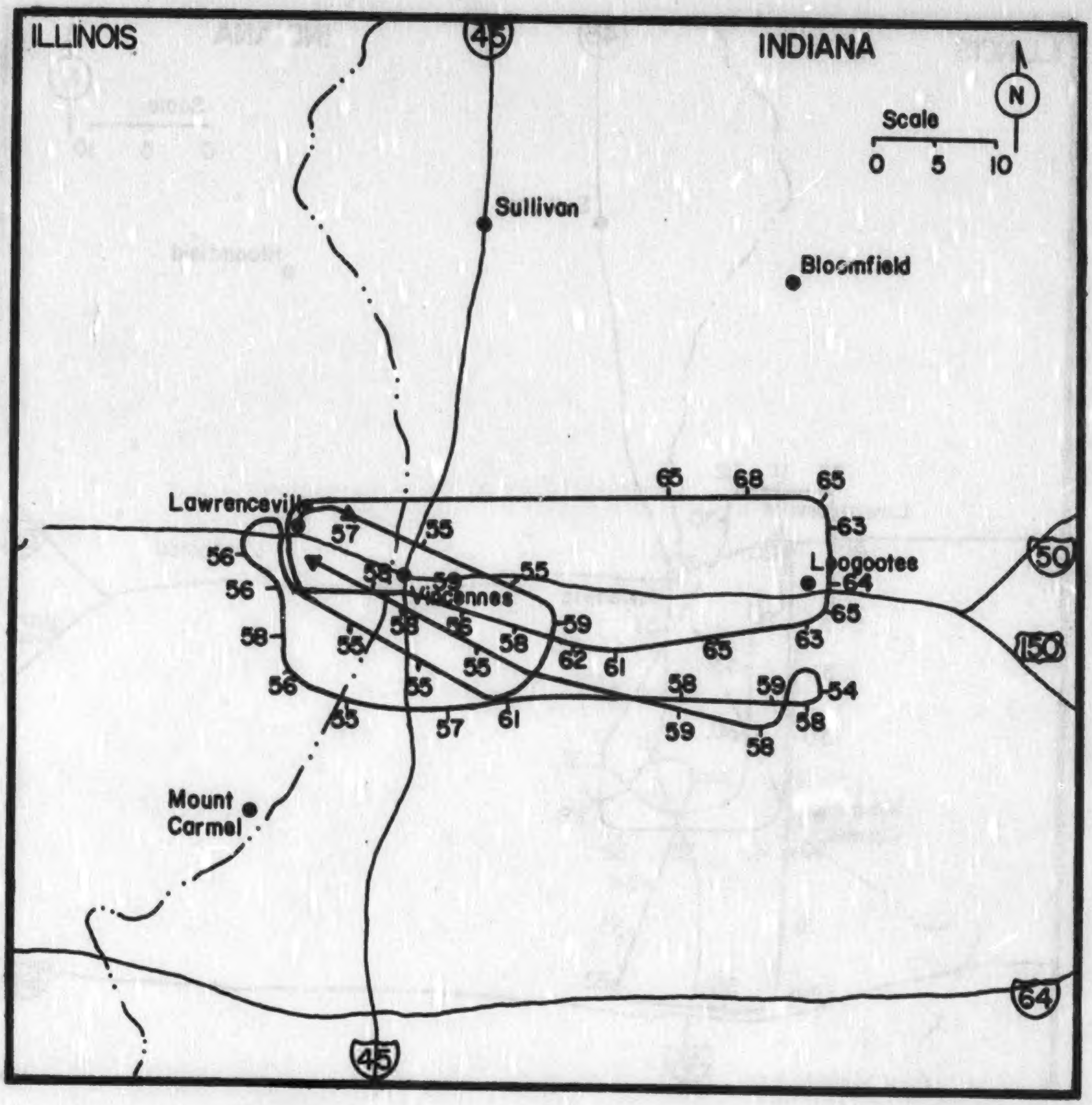

ILLINOIS
INDIANA
45
Scale
0 5 10
N
Sullivan
Bloomfield
Lawrenceville
Vincennes
Loogootes
Mount Carmel
50
150
64
45
65
68
65
63
64
65
63
57
55
56
56
58
58
55
58
55
59
56
58
62
61
65
55
55
56
55
57
61
58
59
54
59
58
58

Figure C-3. Ozone survey flight during afternoon hours on June 15. Wind direction was 280° at 13 mph.

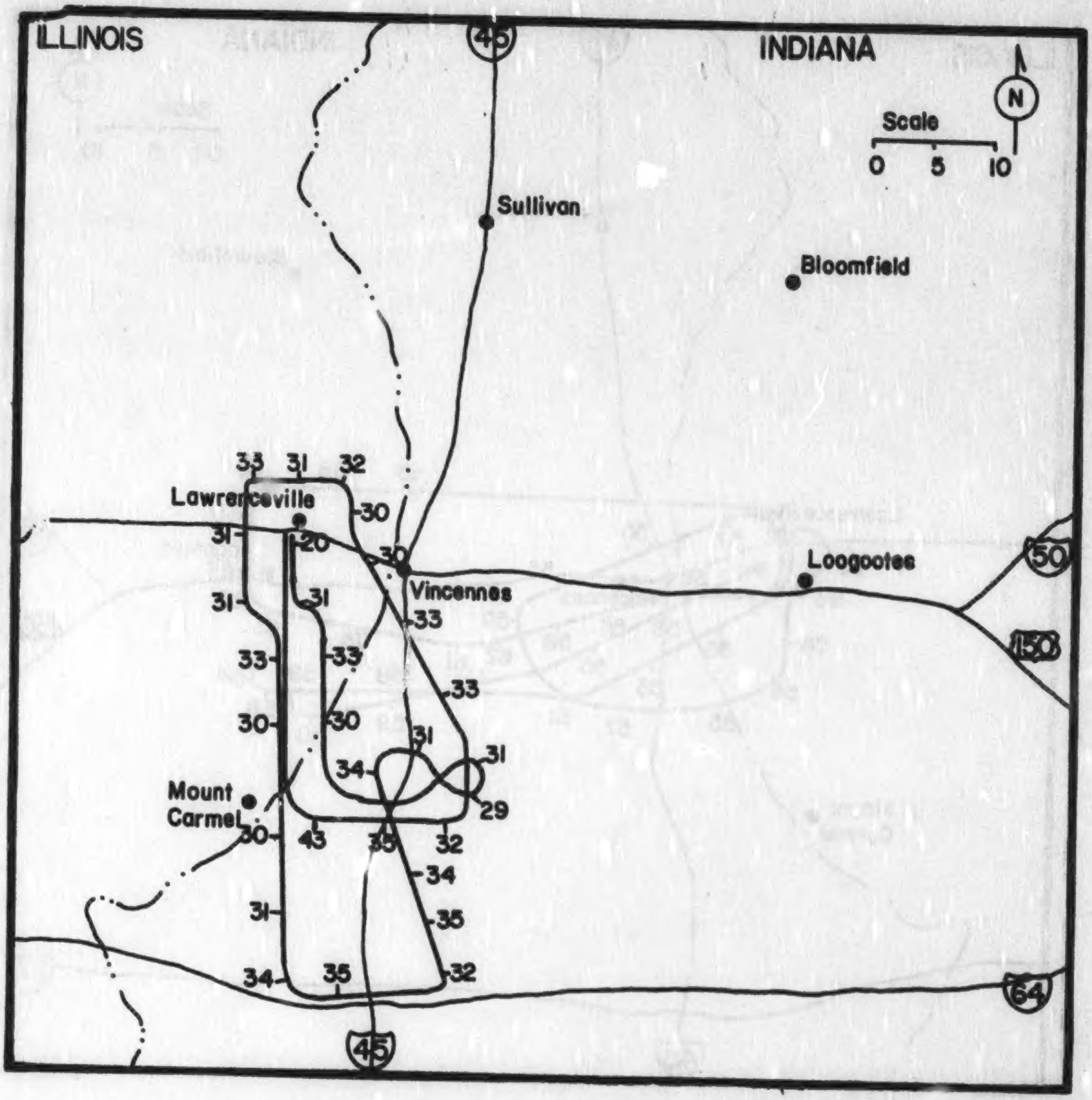

ILLINOIS
INDIANA
45
N
Scale
0
5
10
Sullivan
Bloomfield
33
31
32
Lawrenceville
30
31
20
30
Vincennes
Loogootee
50
31
31
33
150
33
33
33
30
30
31
31
34
29
Mount Carmel
30
43
35
32
34
35
31
34
35
32
64
45

Figure C-4. Ozone survey flight during afternoon hours on June 23. Wind direction was 350° at 15 mph.

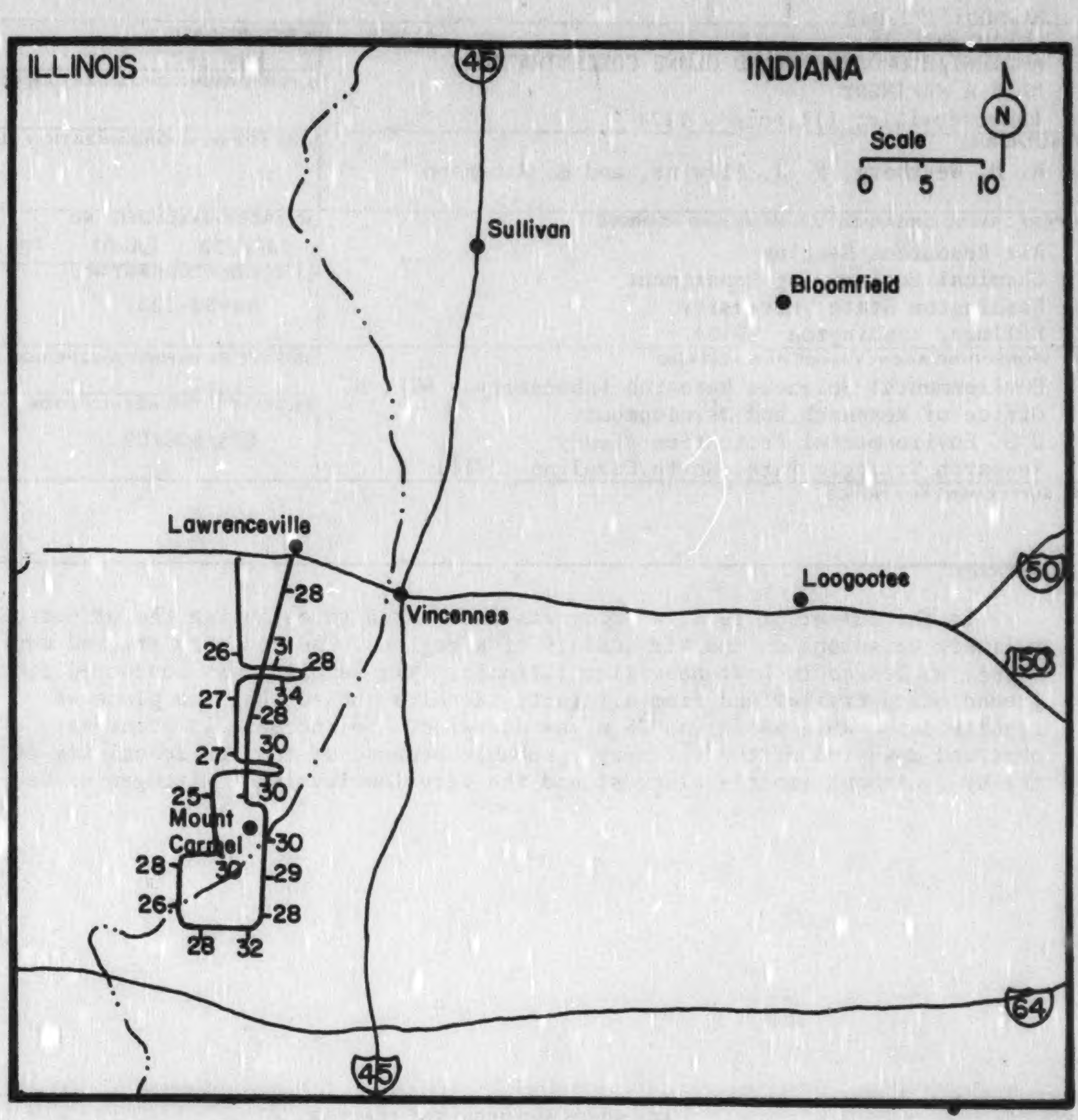

ILLINOIS
INDIANA
N
Scale
0
5
10
45
Sullivan
Bloomfield
Lawrenceville
Vincennes
Loogootee
50
150
28
26
31
28
27
34
28
30
27
30
25
Mount Carmel
30
28
30
29
26
28
28
32
64
45

Figure C-5. Ozone survey flight during afternoon hours on June 24. Wind direction was 350° at 11 mph.